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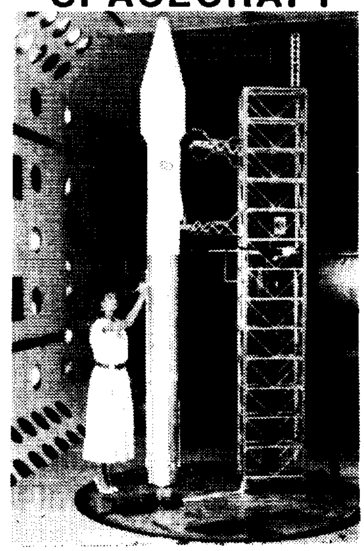
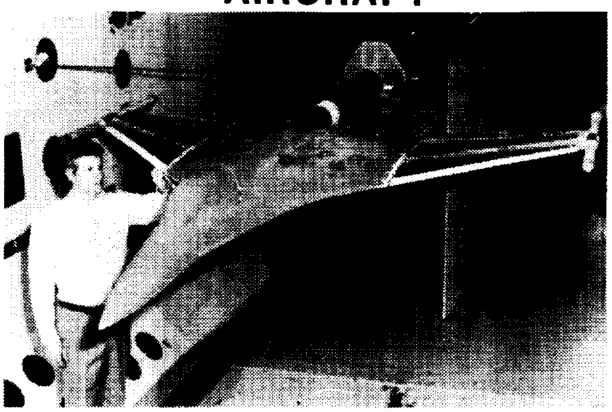
STRUCTURAL DYNAMICS DIVISION RESEARCH AND TECHNOLOGY ACCOMPLISHMENTS FOR F.Y. 1992 AND PLANS FOR F.Y. 1993

Eleanor C. Wynne

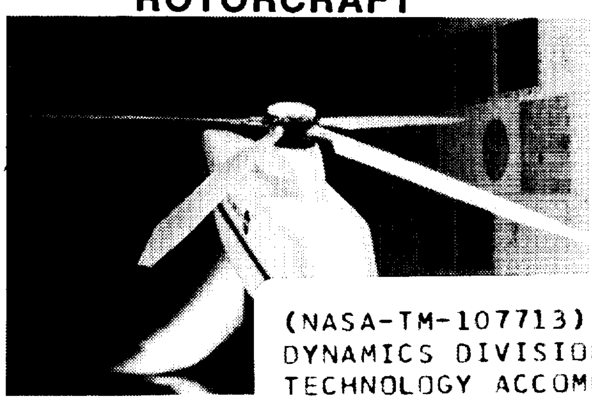
SPACECRAFT



AIRCRAFT



ROTORCRAFT



FACILITIES

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STRUCTURAL DYNAMICS DIVISION

RESEARCH AND TECHNOLOGY ACCOMPLISHMENTS FOR F.Y. 1992

AND PLANS FOR F.Y. 1993

SUMMARY

The purpose of this paper is to present the Structural Dynamics Division's research accomplishments for F.Y. 1992 and research plans for F.Y. 1993. The work under each branch/office (technical area) is described in terms of highlights of accomplishments during the past year and plans for the current year as they relate to 5-year plans and the objectives for each technical area. This information will be useful in program coordination with other government organizations, universities, and industry in areas of mutual interest.

ORGANIZATION

The Langley Research Center is organized into directorates as shown in figure 1, page 32. Directorates are subdivided into divisions and offices. The Structural Dynamics Division of the Structures Directorate consists of five branches and one office as shown in figure 2, page 33. This figure lists the key people in the Division which consists of 77 NASA civil servants and 12 U. S. Army civil servants of the Vehicle Structures Directorate, U. S. Army Research Laboratory, collocated at the Langley Research Center. Phone numbers for each organization are given. Each branch/office represents a technical area and focused activities under the technical areas are shown in the figure.

The Division conducts analytical and experimental research in six technical areas to meet technology requirements for advanced aerospace vehicles. The research thrusts are given in figure 3, page 34. The Configuration Aeroelasticity Branch (CAB), Unsteady Aerodynamics Branch (UAB), and Aeroservoelasticity Branch (ASEB) all work in the area of the prediction and control of aeroelastic stability and response of aircraft, rotorcraft, and space launch vehicles. The Landing and Impact Dynamics Branch (LIDB) conducts research on the crash dynamics of aircraft structures and on the technology for improving the safety and handling performance of aircraft during ground operations. The Spacecraft Dynamics Branch (SDB) conducts research on the prediction and control of the structural dynamic response of complex space structures. The Interdisciplinary Research Office (IRO) develops methodology for aerospace vehicle design with emphasis on providing analytical methods to quantify interactions among engineering disciplines and to exploit this interaction for improved performance.

FUNCTIONAL STATEMENT

The Division conducts analytical and experimental research in the areas of configuration aeroelasticity, aeroservoelasticity, unsteady aerodynamics, impact and landing dynamics, spacecraft dynamics, and multidisciplinary design to meet technology requirements for advanced atmospheric and space flight vehicles. It also develops analytical and computational methods for predicting and controlling aeroelastic instabilities, deformations, vibrations, and dynamic response. The Structural Dynamics Division investigates the interaction of structure with aerodynamics and control systems, landing dynamics, impact dynamics, and resulting structural response. It evaluates structural configurations embodying new material systems and/or advanced design concepts for general application and for specific classes of new aerospace vehicles. The Division develops methodology for aircraft and spacecraft design using integrated multidisciplinary methods. A broad spectrum of test facilities to validate analytical and computational methods and advanced configuration and control concepts are used. Research techniques to demonstrate safety from aeroelastic instabilities for new airplanes, helicopters, and space launch vehicles are developed. Test facilities include the Transonic Dynamics Tunnel, the Helicopter Hover Facility, the Impact Dynamics Research Facility, the Aircraft Landing Dynamics Facility, the Space Structures Research Laboratory, and the Structural Dynamics Research Laboratory.

FACILITIES

The Structural Dynamics Division has four major facilities available to support its research as shown in figure 4, page 35.

The Transonic Dynamics Tunnel (TDT) is a maximum Mach 1.2 continuous flow, variable pressure wind tunnel with a 16-square-foot test section which uses either air or heavy gas (R-12) as the test medium. The maximum Reynolds number obtainable is approximately 10 million per foot in heavy gas and 3 million per foot in air. The TDT is a unique "National" facility that is used almost exclusively for testing of aeroelastic phenomena. Semi-span, sidewall-mounted models and full-span, sting-mounted or cable-mounted models are used for aeroelastic studies of fixed wing aircraft. In addition, the Aeroelastic Rotor Experimental System (ARES) test stand is used in the tunnel to study the aeroelastic characteristics of rotor systems. The Helicopter Hover Facility (HHF), located in an adjacent building, is used to set up the ARES test stand in preparation for entry into the TDT and for rotorcraft studies in hover. The TDT Data Acquisition System is capable of simultaneous support of tunnel tests, HHF tests and model checkout in the Calibration Laboratory. A major facility upgrade to improve the heavy gas reclamation system is in the final stages of checkout. Normal operations using air have resumed, as have limited operations using heavy gas.

The Aircraft Landing Dynamics Facility (ALDF) is capable of testing various types of landing gear systems at velocities up to 220 knots on a variety of runway surfaces under many types of simulated weather conditions. The ALDF consists of a 2800-foot-long rail system, a 2.2 million pound thrust propulsion system, two test carriages, and an arresting system. Test articles can be subjected to vertical loads up to 65,000 pounds and sink rates up to 20 feet per second on a variety of runway surface conditions. The facility provides for testing at speeds and sizes pertinent to large transport aircraft, fighter aircraft, and the Space Shuttle Orbiter. A minor construction of facility activity in F.Y. 1992 added a second high-pressure water pump to the propulsion system that has significantly reduced the recycle time between test runs and enhanced the productivity of the facility.

The Impact Dynamics Research Facility (IDRF), which was originally used by the astronauts during the Apollo program for simulation of lunar landings, has been modified to simulate crashes of full-scale aircraft under controlled conditions. The aircraft are swung by cables from an A-frame structure which is approximately 400 feet long and 230 feet high. The impact runway can be modified to simulate other ground crash environments, such as packed dirt, to meet a specific text requirement. Each aircraft is suspended by cables from two pivot points 217 feet off the ground and allowed to swing, pendulum-style, into the ground. The swing cables are separated from the aircraft by pyrotechnics just prior to impact. Length of the swing cables regulates the aircraft impact angle from 0 degrees (level) to approximately 60 degrees. Impact velocity can be varied to approximately 65 mph (governed by the pullback height). Variations of aircraft pitch, roll, and yaw can be obtained by changes in the aircraft's suspension harness attached to the swing cables. Onboard instrumentation data are obtained through an umbilical cable which is hard-wired to the control room at the base of the A-frame. Photographic data are obtained by onboard, ground-mounted, and A-frame mounted cameras. Maximum allowable weight of the aircraft is 30,000 lbs.

Building 1293 facilities are uniquely designed to carry out structures-related research on spacecraft and aircraft structures, equipment, and materials. Recent emphasis on testing capability at low frequencies has allowed the characterizing of spacecraft and high-gain control systems needed to meet pointing requirements. The heights of the labs allow properly suspended models with reduced effects of gravity and the sizes allow simultaneous tests of large structures over long periods of time. It offers controlled environmental conditions including acceleration, thermal radiation, vacuum and several shaker types for actuation and excitation. All areas are television monitored and hard-wired to data acquisition and processing equipment. A 256-channel digital data acquisition and signal processing system is available with on-line test controllers. A variety of auxiliary data logging and signal processing equipment is also available.

The 16-meter Thermal Vacuum Chamber has a 55-foot diameter cylinder, a 64-foot-high hemispherical dome peak, a flat floor and a rotation option of a centrifuge arm or table. The centrifuge is rated at 20,000 lbs, up to 100g, with a 50,000-force-lb capacity and a maximum allowable specimen weight of 2,000 lbs. Access is by two doors; one 18 x 20 feet. A vacuum of 100 microns Hg can be achieved in 160 minutes. Temperature gradients of 100°F are obtained from 250-ft^2 of portable radiant heaters and liquid nitrogen cooled plates.

The Structural Dynamics Research Laboratory is dominated by a 38-foot-high backstop. Test areas available around this backstop are 15 x 35 x 38 feet high and 12 x 12 x 95 feet high. Access to the entire laboratory is provided by spiral stairs, ladders, and platforms.

The Space Structures Research Laboratory (SSRL) is a large open room of 5200-ft^2. There is a work platform 73 feet above the floor with removable decking and a 20 x 30 x 40-foot free-standing gantry for isolated suspension. In one corner there is a vertical 12 x 12-foot backstop. There is a full environmental control system and many platforms accessible for viewing and instrumentation. The control room contains a state-of-the-art data acquisition capability and overlooks the laboratory. The laboratory houses a 1/10-scale space station like model and controls-structures interaction models, including the 55-foot-long Controls-Structures Evolutionary Model, for performing structural dynamics and controls research of space structures.

F.Y. 1992 ACCOMPLISHMENTS

Configuration Aeroelasticity Branch
(Pages 37-61)

The Configuration Aeroelasticity Branch conducts research (fig. 5) to develop the aeroelastic understanding and prediction capabilities to apply new aerodynamic and structural concepts to future flight vehicles and to evaluate the aeroelastic characteristics of new rotor systems. Present activities and future plans for the major activity areas are presented in figure 6.

The Configuration Aeroelasticity F.Y. 1992 accomplishments listed below are highlighted in figures 7 through 16.

Aircraft Aeroelasticity:
- Boeing 777 Flutter Model Test Completed in TDT
- NASP Flexible Fuselage Model Ready for Testing in TDT

Benchmark Models:
- Unsteady Pressure Distributions Measured During Flutter of Benchmark-Model-Program NACA 0012 Model
- Unsteady Pressure Distributions Acquired During Flutter on the Benchmark Supercritical Wing
- Flutter and Flow Characteristics of an Exploratory HSCT Model Determined in TDT

Rotorcraft Aeroelasticity:
- TDT Tests Conducted to Evaluate British Rotor Blade Technology
- TDT Tests Conducted to Evaluate Langley-Designed Slotted Airfoils for Use on Helicopter Rotors

TDT Facility Operations:
- Modifications Completed for the Transonic Dynamic Tunnel Heavy Gas Reclamation System
- Hardware Improvements to Transonic Dynamic Tunnel Data Acquisition System
- Video Dynamic Deformation Measurement System Ready for Use in TDT

Unsteady Aerodynamics Branch
(Pages 63-83)

The Unsteady Aerodynamics Branch (UAB) conducts research (fig. 17) to develop, validate, and apply computational fluid dynamics (CFD) methods for predicting steady and unsteady aerodynamic airloads on and the aeroelastic characteristics of flight vehicles. The Branch also supports research activities aimed at generating experimental databases needed for validating computational methods. In the past, research topics reflected a major emphasis on accurately predicting transonic aeroelastic phenomena, such as wing flutter-speed dip and aileron buzz. Recently, research in the following areas has become important areas of investigation: dynamic vortex-structure interactions, dynamic loads, buffet prediction, and hypersonic aeroelasticity. Emphasis on these latter topics is due to the emerging importance of the high-angle-of-attack maneuvering flight capabilities demonstrated by a number of current high-performance aircraft and to the development of the National Aero-Space Plane. The UAB is developing CFD methodologies based on a number of mathematical formulations to predict this wide range of unsteady aerodynamic and aeroelastic phenomena accurately and efficiently. The mathematical formulations used as the basis of CFD methods developed in the UAB include transonic small disturbance potential, Euler equations, and thin-layer and Reynolds-averaged Navier-Stokes equations. The Branch's research program is outlined in figure 18 which shows the 5-year plan for the development of aerodynamic analysis methods and aeroelastic prediction techniques. The plan also provides for UAB participation in the Structural Dynamics Division's Benchmark Models Program. This experimental effort includes participation in tests in the Transonic Dynamics Tunnel and in pre-test and post-test computational analysis.

Figures 19 through 26 highlight the UAB F.Y. 1992 accomplishments that are listed below.

Transonic Small Disturbance Potential Methods:

- Symmetric and Antisymmetric Flutter Boundaries Predicted for the AFW Wind-Tunnel Model
- Transonic Shock Oscillations Calculated with a New Interacting Boundary Layer Coupling Method
- Flexible Swept Vertical Surface Capability Added to CAP-TSD Aeroelasticity Code

Euler/Navier-Stokes Methods:

- Subsonic/Transonic Flutter Boundary Computed Using Unsteady Euler Aerodynamic Method
- Two-Dimensional Gridless Euler/Navier-Stokes Solution Algorithm Developed
- Three-Dimensional, Unstructured-Grid Euler Method Used for Time-Marching Aeroelastic Analysis
- Euler Flutter Analysis of a Complex Aircraft Configuration Demonstrated Using Unstructured-Grid Methodology
- Simulation of Tail Buffet Using Delta Wing/Vertical Tail Configuration

Aeroservoelasticity Branch

(Pages 85-113)

The Aeroservoelasticity Branch (fig. 27) conducts research to enhance/develop: methodologies for integrating structures, aerodynamics, and controls disciplines into an aeroelastic/aeroservoelastic preliminary design capability; algorithms for designing control systems to prevent undesirable structural and aeroelastic response; nonlinear modeling and analysis methods for accurately determining the aeroelastic characteristics of flexible fixed wing and rotorcraft vehicles in all flight regimes including controlled aircraft undergoing severe thermal changes; hardware and software to conduct near real-time simulation of aeroservoelastic interactions; digital controllers that include multi-input/multi-output, multifunction, multirate, and adaptive control capabilities; and concepts that employ adaptive/smart materials for improving aircraft performance and alleviating undesirable aeroelastic response. In addition, the Branch assists in performing wind-tunnel experiments for obtaining data to validate new and improved methodologies and provides technical support for NASA and DoD projects to insure that the flight envelope of the vehicle is free of unstable aeroelastic phenomena or adverse structural response. The scope of this work is more explicitly identified in figure 28 which shows the Branch's 5-year plan.

The Aeroservoelasticity Branch F.Y. 1992 accomplishments listed below are highlighted in figures 29 through 41.

Design Methodology:
- Multirate Flutter Suppression System Developed for the BACT Wind-Tunnel Model
- Stochastic-Simulation-Based Method for Predicting Time-Correlated Gust Loads Validated
- Hypersonic Aeroelastic Analysis Method Developed Using Steady CFD Aerodynamics
- Implicit Shear Deformation Model Improves Aeroelastic Analysis Capability
- Flutter Suppression Control Laws Designed for the BACT Wind-Tunnel Model Using Classical, LQG, and H_∞ Methods

Analysis Methodology and Applications:
- Digital Controller Systems Developed for the BACT Program
- Aeroelastic Characteristics of NASP Demonstrator Model Identified
- Results of Aeroelastic Analysis of Mach 2.4 HiSAIR Configuration
- Aeroelastic Analysis Tools for HiSAIR Project Verified on Simple Multidisciplinary Design Problem
- Technique to Extract "Unaliased" Power Spectra from Aliased Power Spectra

Active Controls Using Adaptive Materials:
- Buffet Load Alleviation Accomplished Via Piezoelectric Actuation
- Active Control of Panel Flutter Using Piezoelectric Actuators Studied
- Small, Shape Memory Alloy Actuators Suppress Panel Flutter

Landing and Impact Dynamics Branch

Pages (115-133)

The Landing and Impact Dynamics Branch (fig. 42) operates two major facilities, the Aircraft Landing Dynamics Facility (ALDF) for experimental studies of aircraft landing gear systems and components and the Impact Dynamics Research Facility (IDRF) for experimental investigations of the crash response characteristics of metal and composite airframe structures. The landing dynamics group is responsible for research activities aimed at improving the technology needed to assure safe, economical all-weather ground operations and the development of new landing gear systems and concepts. The group coordinates in-house research, grant activities, contract efforts, and joint government-industry programs to achieve the required technology. The impact dynamics group conducts research to obtain a better understanding of the response characteristics of composite airframe components subjected to crash loads and to develop and enhance analytical tools for predicting these response characteristics and for providing insights into the fundamental physics associated with the structural behavior of these airframe components. In-house research, grant efforts, and contract activities are utilized to develop structural concepts that exhibit superior energy absorption characteristics that result in reduced crash loads and to develop the technology needed to analyze these structural responses. The work of the Landing and Impact Dynamics Branch is more clearly identified in figure 43 which shows the 5-year plan for the disciplines in both landing and impact dynamics along with their expected results.

The Landing and Impact Dynamics Branch F. Y. 1992 accomplishments are highlighted in figures 44 to 51.

Impact Dynamics:

- Accurate Structural Failure Prediction of Composite Fuselage Components Under Crash Loads–An Analytical Challenge
- Curved Beam Finite Element Developed for Optimization Process of Composite Aircraft Fuselage Frames
- Energy Absorbing Beam Design for Composite Aircraft Subfloor
- High Failure Loads of Metal Subfloor in a Composite Fuselage Emphasizes Need for Energy Absorbing Structure

Landing Dynamics:

- New Tire-Contact-Friction Algorithm Correlated with Space Shuttle Nose-Gear Tire Experimental Results
- F-4 Bias-Ply and Radial-Belted Tire Stiffness Values Defined
- Landing Systems Research Aircraft Developed
- Cornering Performance of 40 X 14 Bias-Ply and Radial-Belted Tires Evaluated on Wet Concrete Paver Block Surfaces

Spacecraft Dynamics Branch

(Pages 135-175)

The Spacecraft Dynamics (fig. 52) conducts research and focused technology studies on the dynamics and control of flexible spacecraft. Analysis and prediction methods are developed for application to such spacecraft as Space Station Freedom, Earth-observing science platforms, and Solar System exploration spacecraft. Methods are verified and improved through experiments on research hardware. Advanced test and data analysis methods for improving the accuracy and speed of ground tests to simulate on-orbit behavior and/or to verify spacecraft and spacecraft components for flight are also developed. Significant ongoing emphasis is on interdisciplinary experiments on the control of flexible spacecraft, scale models for spacecraft development, and advanced algorithms for system identification. On-orbit verification methods and experiments are a long-term goal. The scope of this work is more explicitly identified in figure 53 which shows the 5-year plan of the organization's major thrusts and their expected result.

The Spacecraft Dynamics Branch F.Y. 1992 accomplishments listed below are highlighted in figures 54 through 71.

Controls-Structures Interaction:

- Passive Damping Stabilization of Active Controller
- Second-Order Observer Based Control
- Magnetostrictive Strut Concept Developed Under Phase 1 SBIR
- CEM Phase-1 Vibration Suppression Using Piezoelectric Actuators

- Performance Improvements for the CSI CEM Real-Time Control System
- MACE System Identification Studies
- Real-Time Simulation Evaluation of RMS Active Damping Augmentation
- Upper Atmosphere Research Satellite (UARS) Disturbance Experiment

Dynamic Scale Model Technology:
- Test/Analysis Correlation of DSMT HMB-2R Space Station Model Completed
- Eight-Bay Damage Location Tests Verify New Eigenstructure Assignment Method
- Space Station Freedom Pre-Integrated Truss Scale Model Design Study Initiated
- Suspension Devices Evaluated For Spacecraft Ground Vibration Testing

Space Station Freedom - Modal Identification Experiment:
- Laboratory Simulations Demonstrate Feasibility of On-Orbit Modal Test
- Model Reduction Procedures Implemented for Test/Analysis Correlation
- Early Modal Identification Experiment Feasibility Determined

Base Research:
- Flexible Manipulator Testbed Installed
- A Newly Developed Observer/Controller Identification (OCID) Technique Successfully Predicts Aircraft Flutter From Stable Closed-Loop Tests
- Adaptive Control Using On-Line Identification Demonstrated

Interdisciplinary Research Office
(Pages 177-199)

The Interdisciplinary Research Office (fig. 72) conducts research aimed at the development, validation, and application of analytical methods for aerospace vehicle design wherein the interactions among all appropriate disciplines are accounted for and exploited. The research program includes the areas of optimization methods, sensitivity analysis, approximate and design-oriented analysis, proper accounting for discipline coupling in analysis and design, strategies for decomposing large complex problems into manageable subproblems, and applications to problems of agency interest. The F.Y. 92 application areas include high-speed aircraft, rotorcraft, and controls-structure integrated design of spacecraft. The 5-year plan for the research program shown in figure 73 indicates the future activities and their goals.

The Interdisciplinary Research Office F.Y. 1992 accomplishments listed below are highlighted in figures 74 through 81.

Optimization Methods:
- Optimization of Wing Bending Material with Flexible Loads for HiSAIR Mach 2.4 Transport Configuration
- Aerodynamic Sensitivity Analysis Using Automatic Differentiation Demonstrated for Helicopter Rotors
- Active Strut Placement Tested on CSI Evolutionary Model
- Controlled Space Structure Design Demonstrates Strengths of Global Sensitivity Approach

- Automatic Differentiation Adapted and Evaluated as a Tool for Engineering Design
- Neural Nets Offer Significant Payoffs in Optimization
- Aerodynamic Performance of Rotor Blades Computed Using Neural Networks
- Application of a Neural Network as a Potential Aid in Predicting NTF Pump Failure

PUBLICATIONS

The F.Y. 1992 accomplishments of the Structural Dynamics Division resulted in a number of publications. The publications are listed below by organization in the categories of journal publications, formal NASA reports, conference presentations, contractor reports, technical briefs, and patents.

Division Office

Journal Publications:

1. Doggett, Robert V., Jr.; and Soistmann, David L.: Low-Speed Characteristics of Some Simple Low-Aspect-Ratio Delta Wing Models. Journal of Aircraft, Vol. 29, March-April 1992, pp. 273-279.

Formal NASA Reports:

2. Wynne, Eleanor C.: Structural Dynamics Division Research and Technology Accomplishments for F.Y. 1992 and Plans for F.Y. 1993. NASA TM-104188, January 1992, 210 p.

Conference Presentations:

3. Abel, Irving: Research and Applications in Structural Dynamics and Aeroelasticity. Presented at 18th ICAS Congress, September 20-25, 1992, Beijing, China. ICAS Paper No. 92-6.3.1.

Configuration Aeroelasticity Branch

Journal Publications:

4. Cole, Stanley R.; and Henning, Thomas L.: Dynamic Response of a Hammerhead Launch Vehicle Wing-Tunnel Model. Journal of Spacecraft and Rockets, Vol. 29, No. 3, May-June 1992, pp. 379-385.

5. Cole, Stanley R.: Aeroelastic Effects of Spoiler Surfaces on a Low-Aspect-Ratio Rectangular Wing. Journal of Aircraft, Vol. 29, No. 5, September-October 1992, pp. 768-773.

Formal NASA Reports:

6. Rivera, José A. Jr.; Dansberry, Bryan E.; Durham, Michael H.; Bennett, Robert M.; and Silva, Walter: Pressure Measurements On A Rectangular Wing With A NACA 0012 Airfoil During Conventional Flutter. NASA TM 104211, July 1992.

7. Seidel, David A.; Sandford, Maynard C.; and Eckstrom, Clinton V.: Unsteady-Pressure and Dynamic-Deflection Measurements on an Aeroelastic Supercritical Wing. NASA TM 4278, December 1991.

8. Wilkie, W. Keats; Langston, Chester W.; Mirick, Paul H.; Singleton, Jeffrey D.; Wilbur, Matthew L.; and Yeager, William T. Jr.: An Experimental Study of the Sensitivity of Helicopter Rotor Blade Tracking to Root Pitch Adjustment in Hover. NASA TM 4313. AVSCOM Technical Report 91-B-017, December 1991.

Conference Presentations:

9. Dansberry, Bryan E.: Dynamic Characteristics of a Benchmark Models Program Supercritical Wing. Presented at the AIAA/ASME/ASCE/AHS/ASC 33rd Structures, Structural Dynamics, and Materials Conference, Dallas, Texas, April 13-15, 1992. AIAA Paper No. 92-2368.

10. Rivera, José A., Jr.; Dansberry, Bryan E.; Bennett, Robert M.; Durham, Michael H.; and Silva, Walter A.: NACA 0012 Benchmark Model Experiment Flutter Results With Unsteady Pressure Distributions. Presented at the AIAA/ASME/ASCE/AHS/ASC 33rd Structures, Structural Dymamics, and Materials Conference, Dallas, Texas, April 13-15, 1992. AIAA Paper No. 92-2396.

11 Rodgers, John P.: Aerothermoelastic Analysis of a NASP-Like Vertical Fin. Presented at the AIAA/ASME/ASCE/AHS/ASC 33rd Structures, Structural Dynamics, and Materials Conference, Dallas, Texas, April 13-15, 1992. AIAA Paper No. 92-2400.

Contractor Reports:

12 Young, M. I.: Structural Dynamics and Vibrations of Damped, Aircraft-Type Structures. (NASA-18585 Vigyan, Inc.) NASA CR 4424, February 1992, 128 p.

Other Reports:

13. Kehoe, Michael W.; and Ricketts, Rodney H.: Getting Up to Speed in Hypersonic Structures. Aerospace America, September 1992.

Unsteady Aerodynamics Branch

Journal Publications:

14. Batina, J. T.: Implicit Flux-Split Euler Schemes for Unsteady Aerodynamic Analysis Involving Unstructured Dynamic Meshes, AIAA Journal, Vol. 29, No. 11, November 1991, pp. 1836-1843.

15. Batina, J. T.: A Finite-Difference Approximate-Factorization Algorithm for Solution of the Unsteady Transonic Small-Disturbance Equation, NASA TP 3129, January 1992, 36 p.

16. Batina, J. T.: "Implicit Upwind-Euler Solution Algorithms for Unstructured-Grid Applications," Computational Fluid Dynamics '92, Elsevier Science Publishers B. V., Amsterdam, The Netherlands, 1992.

17. Kleb, W. L.; Batina, J. T.; and Williams, M. H.: Temporal Adaptive Euler/Navier-Stokes Algorithm for Unsteady Aerodynamic Analysis of Airfoils Using Unstructured Dynamic Meshes, AIAA Journal, Vol. 30, No. 8, August 1992, pp. 1980-1985.

18. Rausch, R. D.; Batina, J. T.; and Yang, H. T.: Spatial Adaptation of Unstructured Meshes for Unsteady Aerodynamic Flow Computations, AIAA Journal, Vol. 30, No. 5, May 1992, pp. 1243-1251.

19. Robinson, B. A.; Batina, J. T.; and Yang, H. T.: Aeroelastic Analysis of Wings Using the Euler Equations With a Deforming Mesh, Journal of Aircraft, Vol. 28, No. 11, November 1991, pp. 781-788.

Formal NASA Reports:

20. Batina, J. T.: A Gridless Euler/Navier-Stokes Solution Algorithm for Complex Two-Dimensional Applications, NASA TM 107631, June 1992.

21. Howlett, J. T.: Calculation of Unsteady Transonic Flows With Mild Separation by Viscous-Inviscid Interaction, NASA TP 3197, June 1992, 37 p.

Conference Presentations:

22. Batina, J. T.; Lee, E. M.; Kleb, W. L.; and Rausch, R. D.: Unstructured-Grid Methods Development for Unsteady Aerodynamic and Aeroelastic Analyses. Presented at the AGARD Structures and Materials Panel Specialist's Meeting on Transonic Unsteady Aerodynamics and Aeroelasticity, San Diego, California, October 9-11, 1991.

23. Batina, J. T.: A Fast Implicit Upwind Solution Algorithm for Three-Dimensional Unstructured Dynamic Meshes. Presented at the AIAA 30th Aerospace Sciences Meeting, Reno, Nevada, January 6-9, 1992. AIAA Paper No. 92-0447. Also available as NASA TM 104186, December 1991.

24. Batina, J. T.: CFD Methods Development Considerations for Unsteady Aerodynamic Analysis. Presented at the Workshop on Computational Aeroacoustics, NASA Langley Research Center, Hampton, Virginia, April 6-9, 1992. Also available as NASA TM 107644, July 1992.

25. Batina, J. T.: Progress in Unstructured-Grid Methods Development for Unsteady Aerodynamic Applications. Presented at the 7th IMACS International Conference on Computer Methods for Partial Differential Equations, Rutgers University, New Brunswick, New Jersey, June 22-24, 1992. Also available as NASA TM 107643, July 1992.

26. Batina, J. T.: Implicit Upwind-Euler Solution Algorithms for Unstructured-Grid Applications. Presented at the First European Computational Fluid Dynamics Conference, Brussels, Belgium, September 7-11, 1992. Also available as NASA TM 107645, July 1992.

27. Bennett, R. M.; Eckstrom, C. V.; Rivera, J. A., Jr.; Dansberry, B. E.; Farmer, M. G.; and Durham, M. H.: The Benchmark Aeroelastic Models Program - Description and Highlights of Initial Tests, Paper No. 25 in AGARD-CP-507, "Transonic Unsteady Aerodynamics and Aeroelasticity," March 1992. Presented at the 73rd Meeting of the Structures and Materials Panel, San Diego, California, October 9-11, 1991. Also available as NASA TM 104180, October 1991.

28. Edwards, J. W.: Current Status of Computational Methods for Transonic Unsteady Aerodynamics and Aeroelastic Applications, Paper No. 1 in AGARD-CP-507, "Transonic Unsteady Aerodynamics and Aeroelasticity," March 1992. Presented at the 73rd Meeting of the Structures and Materials Panel, San Diego, California, October 9-11, 1991.

29. Edwards, J. W.: Technical Evaluation Report on 1991 Specialists' Meeting on "Transonic Unsteady Aerodynamics and Aeroelasticity," Paper No. T in AGARD-CP-507, "Transonic Unsteady Aerodynamics and Aeroelasticity," March 1992.

30. Edwards, J. W.: Transonic Shock Oscillations Calculated with Interacting Boundary Layer Theory. Presented at the Aerospace Flutter and Dynamics Council Meeting, Williamsburg, Virginia, April 30, 1992.

31. Hooker, J. R.; Batina, J. T.; and Williams, M. H.: Spatial and Temporal Adaptive Procedures for the Unsteady Aerodynamic Analysis of Airfoils Using Unstructured Meshes. Presented at the AIAA 10th Applied Aerodynamics Conference, Palo Alto, California, June 22-24, 1992. AIAA Paper No. 92-2694. Also available as NASA TM 107635, July 1992.

32. Rausch, R. D.; Batina, J. T.; and Yang, H. T. Y.: Three-Dimensional Time-Marching Aeroelastic Analyses Using an Unstructured-Grid Euler Method. Presented at the 33rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, Dallas, Texas, April 13-15, 1992. AIAA Paper No. 92-2506. Also available as NASA TM 107567, March 1992.

33. Silva, W. A.; and Bennett, R. M.: Investigation of the Aeroelastic Stability of the AFW Wind-Tunnel Model Using CAP-TSD, Paper No. 20 in AGARD-CP-507, "Transonic Unsteady Aerodynamics and Aeroelasticity," March 1992. Presented at the 73rd Meeting of the Structures and Materials Panel, San Diego, California, October 9-11, 1991. Also avaialbe as NASA TM 104142, October 1991.

34. Silva, W. A.; and Bennett, R. M.: Further Investigations of the Aeroelastic Behavior of the AFW Wind-Tunnel Model Using Transonic Small Disturbance Theory. Presented at the AIAA Dynamics Specialists Conference, Dallas, Texas, April 16-17, 1992. AIAA Paper No. 92-2082. Also available as NASA TM 107576, March 1992.

35. Whitlow, W., Jr.: Unsteady Aerodynamics Branch Research Program Overview. Presented at the Aerospace Flutter and Dynamics Council Meeting, Williamsburg, Virginia, April 30, 1992.

36. Woodard, P. R.; Batina, J. T.; and Yang, H. T. Y.: Quality Assessment of Two- and Three-Dimensional Unstructured Meshes and Validation of an Upwind Euler Flow Solver. Presented at the AIAA 30th Aerospace Sciences Meeting, Reno, Nevada, January 6-9, 1992. Also available as NASA TM 104215, February 1992.

Aeroservoelasticity Branch

Journal Publications:

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F.Y. 1993 PLANS

Configuration Aeroelasticity Branch
(Pages 201-207)

Figure 82 summarizes accomplishments planned for F.Y. 1993 selected from the Branch's broad based research program on dynamic and aeroelastic phenomena of aircraft and rotorcraft. A large portion of this work is associated with wind-tunnel tests in the Langley TDT with companion theoretical studies. Research studies are planned for both rotorcraft and aircraft.

Testing related to aircraft aeroelasticity will include two cooperative programs with Cessna and Gulfstream to study the flutter characteristics of a Citation X wing model and of a G-V wing model in the TDT. Also, two joint studies are underway with Boeing/Seattle and General Dynamic/Fort Worth. One involves a TDT test of a large transport type wing model to investigate phenomena which cause limit cycle oscillations (LCO). Another study involves a TDT test of a high performance fighter to evaluate the effects of free play on control surface flutter. NASP Government Work Package studies include a full-span model for studying fuselage flexibility effects on flutter in the TDT, a wing model for studying static divergence, and a panel model for studying panel flutter. These last two models will be tested in the Langley Supersonic Unitary Plan Wind Tunnel.

The Benchmark Models Program will continue with the design, fabrication, and testing of a series of four instrumented rigid rectangular wing models. All models have two chords of unsteady pressure instrumentation totaling 80 transducers to record unsteady pressures during flutter. These rigid rectangular models are designed for testing on a flexible mount system with pitch and plunge degrees of freedom. The first two models, one with a NACA 0012 airfoil and the other a supercritcal airfoil SC(2)-0414, have been successfully tested with data reduction and formal documentation underway. Fabrication of the third model, with a 64A010 airfoil, is completed with instrumentation to follow. The fourth model, similar to the NACA 0012 model but includes an active trailing edge control surface and two spoilers (upper and lower surface), is ready to be tested. Two additional models of the High-Speed Civil Transport (HSCT) have been added to the Benchmark Models Program. One model is relatively rigid and will be tested both statically on a force balance and dynamically on a pitch and plunge mount. The second is a flexible aeroelastically scaled model which will be tested up to flutter.

The rotorcraft aeroelasticity work will include testing of a Parametric Bearingless Hub (PBH) using the Aeroelastic Rotor Experimental System (ARES) testbed. The BERP and the HIMARCS Phase I blades have been tested successfully with data reduction and formal documentation of results now underway. An automatic control for the ARES has been tested successfully and will increase efficiency in all future ARES program testing. Development of the ARES 1.5 and ARES 2 testbeds will continue with initial testing of the ARES 2 to take place in the Helicopter Hover Facility. A rotating balance for the ARES testbeds has been fabricated and will be integrated in future ARES tests. A third-generation hingeless rotor hub (AHRO-III) has been designed and preparations are underway to begin fabrication. Fabrication will continue on a set of optimized blades as part of the Langley rotorcraft optimization/validation effort.

The TDT facility operations group will immediately begin an engineering study to determine candidate replacement heavy gases for use as a test medium in the TDT. The Data Acquisition System at the TDT will be upgraded to larger and faster mainframes with integrated workstations to meet the demanding current and future aeroelastic test requirements.

Highlights of proposed F.Y. 1993 research for the three technical areas of Aircraft Aeroelasticity, Benchmark Models, and Rotorcraft Aeroelasticity are shown in figures 83 through 85.

Unsteady Aerodynamics Branch
(Page 208)

Figure 86 outlines the F.Y. 1993 plans for the Unsteady Aerodynamics Branch (UAB). Researchers will continue to enhance the capabilities of the CAP-TSD code, and UAB, industry, and university researchers will apply the code to aeroelastic problems of national interest in order to further define its range of accuracy. The enhancements will be an inverse boundary layer method and validated flexible fuselage and flexible, swept vertical tail capabilities. As part of this activity, the Branch will contract for programmer support of the CAP-TSD code. Unsteady aerodynamic and aeroelastic response calculations will be performed using solution procedures based on the Euler and Navier-Stokes equations. This will include the validation of methods for predicting vortex-dominated and viscous-dominated flows and for predicting the aeroelastic response phenomena characterized by such flows. The solution procedures will be developed using structured grid, unstructured grid, and gridless flow solvers. Correlations of computed results from UAB-developed codes with other theoretical solutions and with experimental data will help to evaluate and validate the computational methods. The Branch will continue to provide support for the Benchmark Models Program by participating in wind-tunnel tests and providing pretest and post-test computational analysis. UAB will serve as the lead organization for designing the high-speed civil transport benchmark model.

Aeroservoelasticity Branch
(Pages 209-223)

Figure 87 lists the major tasks being pursued by the Aeroservoelasticity Branch in F.Y. 1993. In the Design Methodology area activities to design multirate, multifunction digital controllers for flutter and gust loads control using advanced algorithms and unconventional control surfaces will continue. Plans are to test these concepts on the Benchmark Active Controls Testing (BACT) model in the Transonic Dynamics Tunnel during F.Y. 1993 and F.Y. 1994. The development of an integrated multidisciplinary design methodology (HiSAIR, High-Speed Airframe Integration Research Project) will continue. The Branch objectives in this effort are to include aeroelasticity and ASE in the preliminary design activity of flight vehicles. In the Analysis Methodology and Applications area the focus of attention involves the use of nonlinear transonic aerodynamics to improve ASE analysis and design methodologies. Activities to develop a simulation laboratory for evaluating, in near-real time, the characteristics of advanced control law designs as well as the functionality of the Branch's digital controllers prior to wind-tunnel testing will continue. In addition, the Matched Filter Theory approach for predicting maximized and time-correlated gust loads for aircraft structural design purposes will be applied to a realistic aircraft with nonlinear control system characteristics. Research is continuing in the development of methods for predicting the aeroelastic characteristics of tiltrotor aircraft and for applying extension-twist coupling for passively controlling blade twist to improve the aerodynamic performance of tiltrotor aircraft. In the area of Adaptive Materials, investigations will continue in extending adaptive materials technology for aeroelastic and ASE applications. Areas to be emphasized include: wing flutter suppression using both piezoelectric actuators and a conventional aerodynamic control surface; panel flutter suppression using shape memory alloys; the use of neural networks for providing adaptive, reconfigurable, flutter suppression when many smart material actuators are used; and the use of smart material actuators to improve the aerodynamic characteristics of airfoils.

Selected highlights of ongoing F.Y. 1993 research are shown in figures 88 through 94.

Landing and Impact Dynamics Branch

(Page 224)

During F.Y. 1993 a major focused technology activity in the area of landing dynamics will be the development of advanced active control landing gear concepts for HSCT applications. Components of this activity include in-house research on a smart orifice concept using F-106 landing gear hardware, a grant activity to study the characteristics of electrorhelogical fluids for possible applications to active control landing gear technology, and a contract activity to develop analysis tools for active control landing gear studies. A shaker table that serves as a runway simulator for the active control landing gear studies will be installed and checked out in F.Y. 93. The smooth runway testing of the H-Type 46 x 18-20 bias-ply and radial-belted aircraft tires for the Surface Traction and Radial Tire (START) Program on ALDF will be completed this year following rolling tire footprint force measurements on three tire sizes. Additional testing on ALDF will evaluate the friction characteristics of bias-ply and radial-belted F-4 main gear tires, define the friction characteristics of several paver block concepts, determine the frictional characteristics of aircraft de-icer fluid contamination of runway surfaces, and investigate the friction performance of various tire sizes and constructions on grooved concrete surfaces. The Branch tire modeling activities will continue with the development of advanced frictional contact algorithms. Figure 95 lists the areas of continuing research activities in landing dynamics for F.Y. 1993.

The major focused technology activity in the impact dynamics area is associated with the Advanced Composite Technology (ACT) Program. In this area a task assignment contract will provide composite test specimens for nondestructive and crash tests. A design support test effort will be completed to provide an energy absorbing general aviation subfloor concept. The concept will be fabricated and installed in a fuselage section and eventually in a Lear Fan airplane. Strength scaling studies of composite structures using a ply scaling approach and failure studies with composite fuselage frames will be completed.

Spacecraft Dynamics Branch
(Page 225)

For F.Y. 1993, the Spacecraft Dynamics Branch will conduct focused technology development and base research along three lines (fig. 96). In the focus technology area of Controls-Structures Interaction (CSI), the CSI Phase-2 Evolutionary Model will be installed in the Space Structures Research Laboratory and used to validate integrated controls-structure methods addressing multi-body dynamics issues. The Phase-2 Model has slightly different geometric configuration from the Phase-0 and -1 Models. At one end of the main truss a double gimbal payload scanning system is mounted and at the other end of the main truss two double gimbal pointing payloads are located. In this configuration, CSI control methodologies associated with scanning and pointing are tested and validated. Following this Phase-2 testing, the model will be evolved to a Phase-2a configuration by the addition of a solar array mast simulator, for which the principle mass moment of inertia is nearly doubled. The technology development will address the resulting instability complications associated with the coupling of the attitude control system with the lower flexible mast modes and examine optimal placement of actuators to achieve acceptable stability margins and performance.

For the Mission Dynamics focus technology area, the use of dynamically scaled structural models of large spacecraft will be further developed. Component and subsystem modal test data for the erectable truss model will be used to validate component mode synthesis analysis methods. Scale model redesign studies will be finalized to reflect the actual Space Station Freedom structural change from an erectable truss to a pre-integrated truss with risk reduction producability. The value of an on-orbit SSF dynamic test for the purposes of verification will be investigated resulting in an experimental requirement and plan.

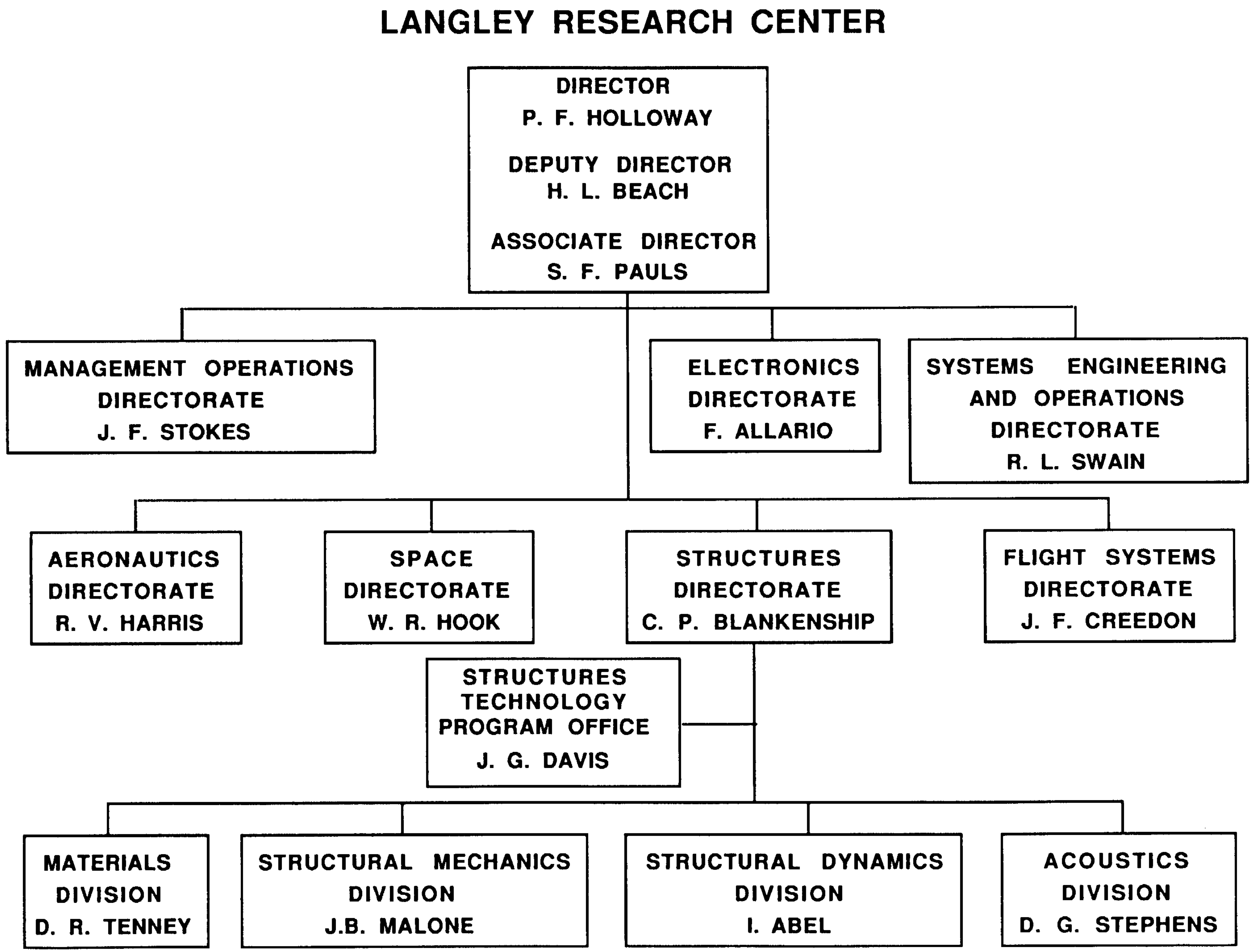
Base research for F.Y. 1993 will emphasize the development of recursive and frequency domain versions of the Observer/Kalman Filter Identification (OKID) method for system identification resulting in a MATLAB toolbox. On-line implementation of the method for use in adaptive control studies is the key objective. A new seven degree-of-freedom flexible manipulator testbed is now on-line and initial testing of a stiff test article has begun leading to the installation of the flexible modifications in the fourth quarter. The two-dimensional large motion suspension device required to support the flexible article will also be installed in the fourth quarter. The development of neural network methodology to perform the nonlinear kinematic control will be investigated.

Interdisciplinary Research Office
(Page 226)

During F.Y. 1993 the emphasis of the research will be on applying and validating integrated multidisciplinary optimization methods for two applications (fig. 97): high-speed aircraft and rotorcraft. In the high-speed aircraft area, Interdisciplinary Research Office researchers will participate in two Langley projects: HiSAIR for optimization of an aircraft design for optimum performance, and HPCCP for developing innovative computational support for engineering design based on heterogeneous computer networks. Near-term work in both projects involves integrating aerodynamics, structures, and performance in the design process. In the rotorcraft activity, emphasis will continue on developing and testing a fully integrated aerodynamic-dynamic-structural optimization procedure for helicopter rotor blades and a comprehensive validation activity for rotorcraft optimization methods in which analytically designed blades will be fabricated and tested to assess optimality and behavior of the designs.

CONCLUDING REMARKS

This publication documents the F.Y. 1992 accomplishments, research, and technology highlights and F.Y. 1993 plans for the Structural Dynamics Division.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STRUCTURAL MECHANICS
DIVISION
J.B. MALONE
STRUCTURAL DYNAMICS
DIVISION
I. ABEL
ACOUSTICS
DIVISION
D. G. STEPHENS

Figure 1.

STRUCTURAL DYNAMICS DIVISION
I. ABEL, CHIEF
R. DOGGETT, ASSISTANT CHIEF
E. WYNNE, TECHNICAL ASSISTANT
L. JOHNSON, SECRETARY
804-864-2934

AEROSERVOELASTICITY BRANCH
T. NOLL, HEAD
B. PERRY, III, ASST. HEAD
804-864-2822

- ANALYSIS METHODS
- DESIGN METHODS
- APPLICATIONS

UNSTEADY AERODYNAMICS BRANCH
W. WHITLOW, HEAD
804-864-2257

- THEORY DEVELOPMENT
- APPLICATIONS
- VALIDATION

CONFIGURATION AEROELASTICITY BRANCH
R. RICKETTS, HEAD
M. SANDFORD, ASST. HD
804-864-1207

- A/C AEROELASTICITY
- R/C AEROELASTICITY

SPACECRAFT DYNAMICS BRANCH
B. HANKS*, HEAD
M. GILBERT, ASST. HEAD
804-864-4324

- CSI GROUND TEST METHODS
- OPTIMAL SPACECRAFT PERFORMANCE
- MISSION DYNAMICS

*TDY to NASA HDQRS until 8/93

INTERDISCIPLINARY RESEARCH OFFICE
J. SOBIESKI, HEAD
H. ADELMAN, DEPUTY
804-864-2802

- DESIGN METHODS
- ALGORITHMS
- APPLICATIONS

LANDING AND IMPACT DYNAMICS BRANCH
J. TANNER, HEAD
H. CARDEN, ASST. HEAD
804-864-1302

- TIRE MODELING
- CRASH DYNAMICS

Figure 2

STRUCTURAL DYNAMICS DIVISION

AERONAUTICS

- TRANSPORT AIRCRAFT
  - AEROELASTICITY
  - LANDING AND IMPACT DYNAMICS
- HIGH PERFORMANCE AIRCRAFT
  - AEROELASTICITY
- ROTORCRAFT
  - AEROELASTICITY
- ANALYTICAL METHODS

SPACE

- LARGE SPACE STRUCTURES
  - STRUCTURAL DYNAMICS
  - CONTROL STRUCTURES INTERACTION

Figure 3.

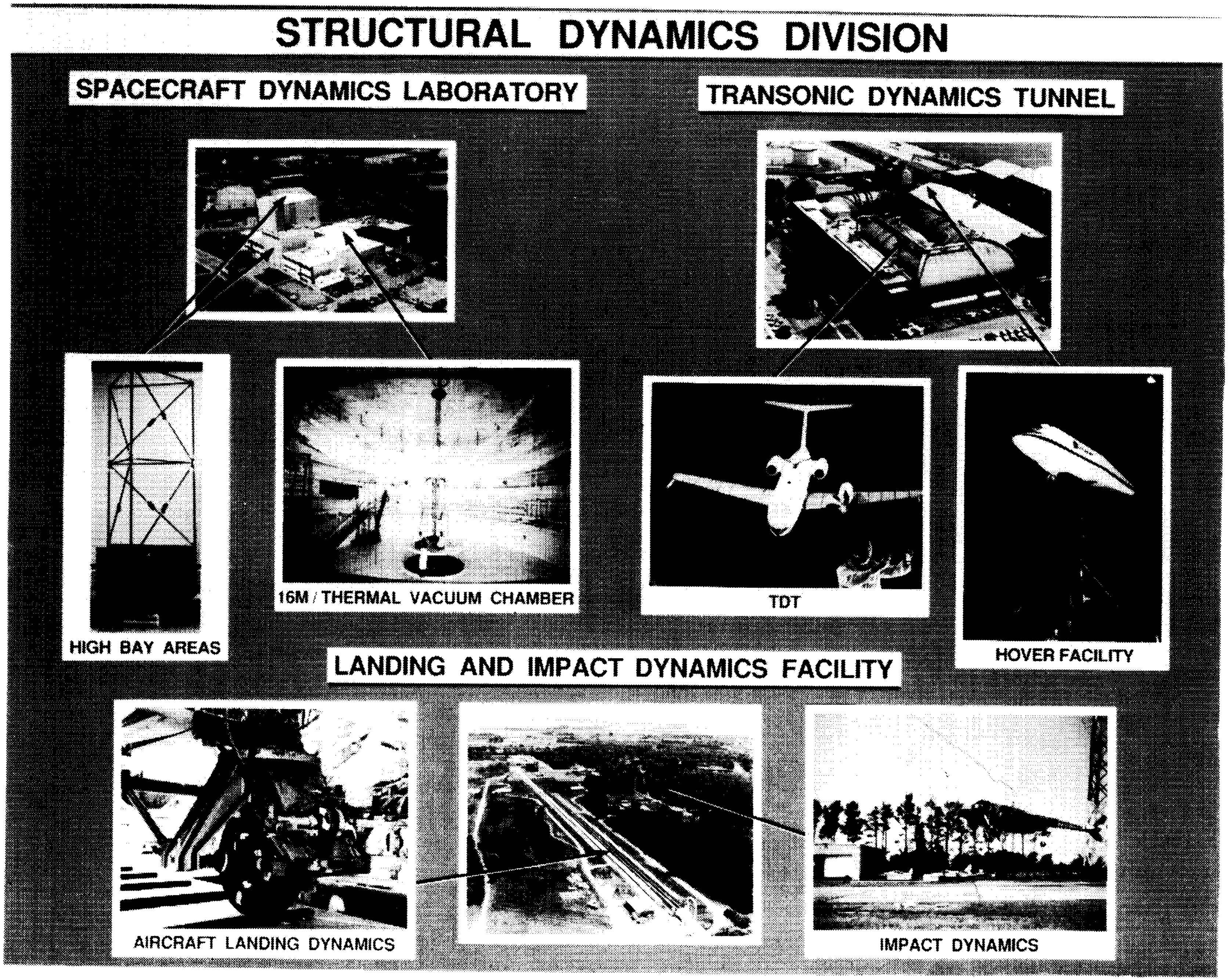
STRUCTURAL DYNAMICS DIVISION
SPACECRAFT DYNAMICS LABORATORY
TRANSONIC DYNAMICS TUNNEL
HIGH BAY AREAS
16M / THERMAL VACUUM CHAMBER
TDT
HOVER FACILITY
LANDING AND IMPACT DYNAMICS FACILITY
AIRCRAFT LANDING DYNAMICS
IMPACT DYNAMICS

Figure 4.

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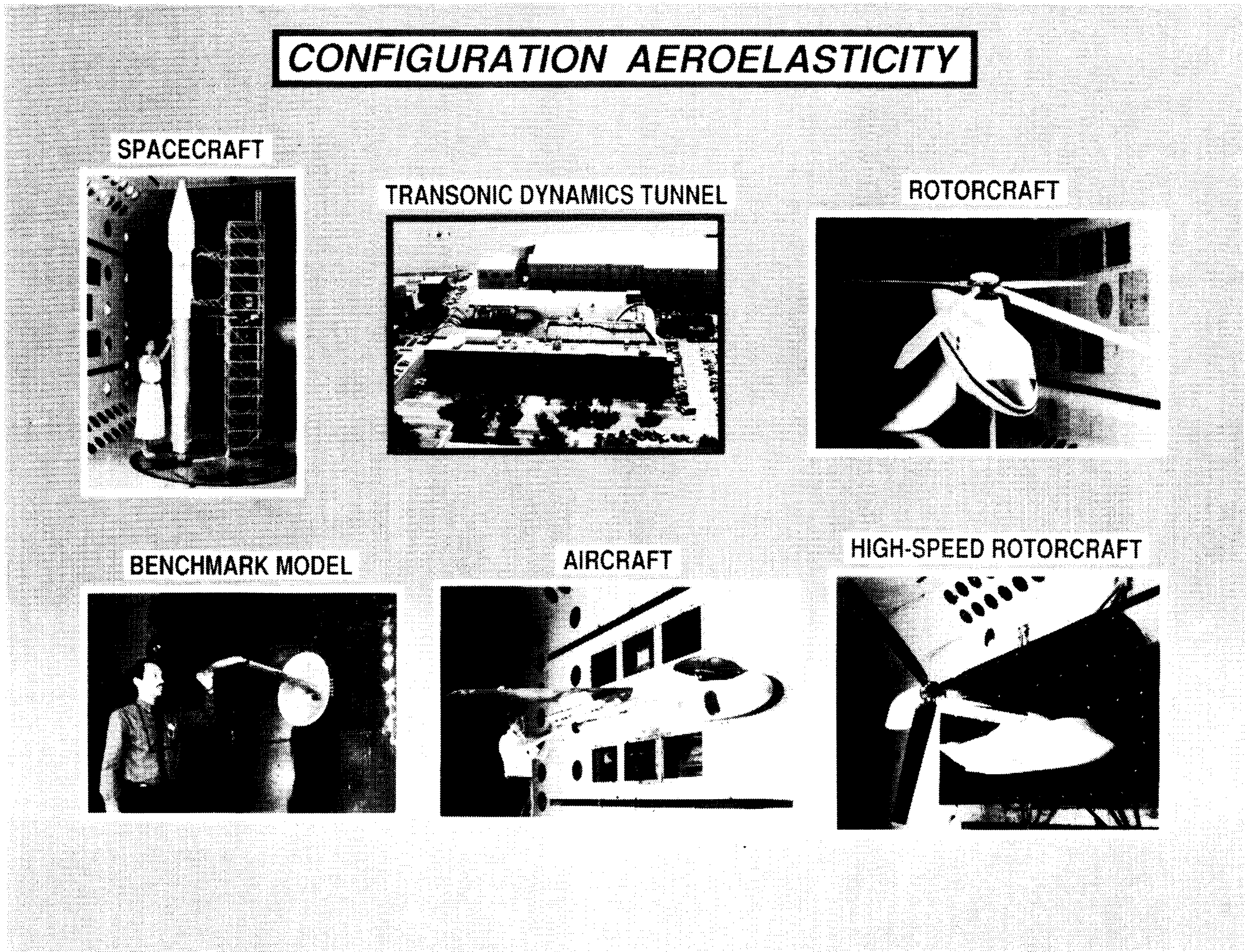
CONFIGURATION AEROELASTICITY
SPACECRAFT
TRANSONIC DYNAMICS TUNNEL
ROTORCRAFT
BENCHMARK MODEL
AIRCRAFT
HIGH-SPEED ROTORCRAFT

Figure 5.

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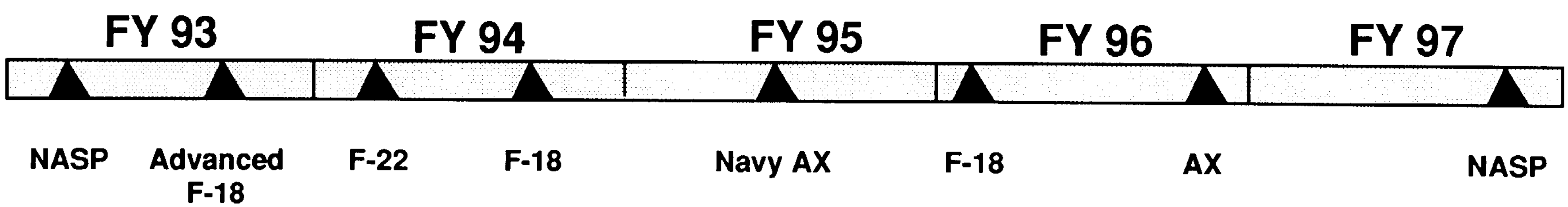
CONFIGURATION AEROELASTICITY FUTURE PLANS (FY 93-97)

GOAL

PREDICTION AND CONTROL OF AEROELASTIC RESPONSE

KEY OBJECTIVES

- VERIFY THAT NEW NASA/DOD FLIGHT VEHICLES HAVE ADEQUATE AEROELASTIC PROPERTIES



- BENCHMARK MODELS

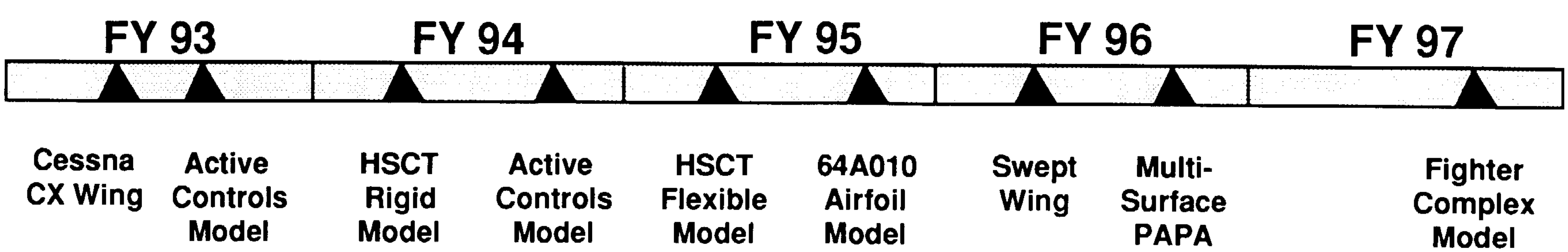


Figure 6 (a).

CONFIGURATION AEROELASTICITY FUTURE PLANS (FY 93-97)

GOAL

PREDICTION AND CONTROL OF AEROELASTIC RESPONSE

KEY OBJECTIVES

- UNDERSTAND AEROELASTIC CHARACTERISTICS OF ADVANCED FLIGHT VEHICLES

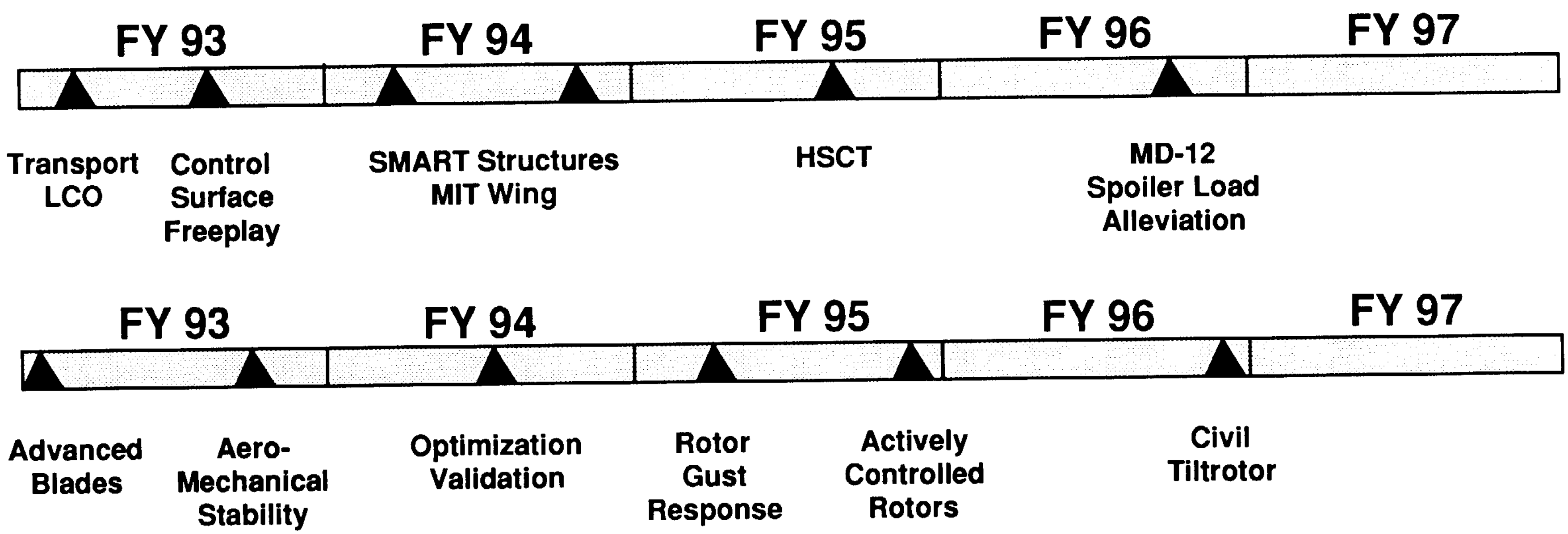


Figure 6 (b).

CONFIGURATION AEROELASTICITY FUTURE PLANS (FY 93-97)

GOAL

PREDICTION AND CONTROL OF AEROELASTIC RESPONSE

KEY OBJECTIVES

- MAINTAIN TDT AS A UNIQUE NATIONAL FACILITY

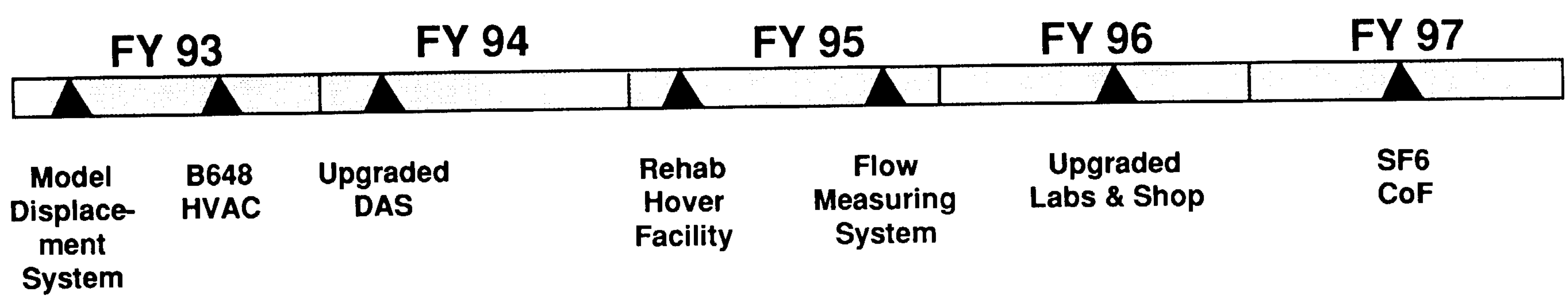


Figure 6 (c).

BOEING 777 FLUTTER MODEL TEST COMPLETED IN TDT

Moses G. Farmer and James R. Florance
Configuration Aeroelasticity Branch

Ellen P. Bullock
Lockheed Engineering & Sciences Co.

RTOP 505-63-50

Research Objective: Commercial transport aircraft must be designed so that flutter will not occur within the flight envelope plus a 20-percent safety margin. Traditionally, wind-tunnel model tests have played an important role in the flutter certification process of new designs. To this end, the objective of the present study was to provide wind-tunnel flutter data for use in ensuring that the wing of the Boeing 777 airplane will be safe from flutter.

Approach: A dynamically scaled semispan aeroelastic model of the 777 wing was tested in heavy gas (R-12) at the Langley Transonic Dynamics Tunnel (TDT) as part of the flutter clearance program. A photograph of the model installed in the TDT is shown at the left in the figure. The rigid fuselage half-body simulated the effect that the aircraft fuselage had on the flow over the wing. The model was attached to a sidewall turntable that could be remotely operated to change the model angle of attack. The model engine nacelle was designed so that the mass flow through the aircraft engine would be simulated. The model was designed so that the amount of simulated fuel in the wing and the stiffness of the engine pylon could be changed remotely so that manual adjustments were unnecessary, thus expediting the testing.

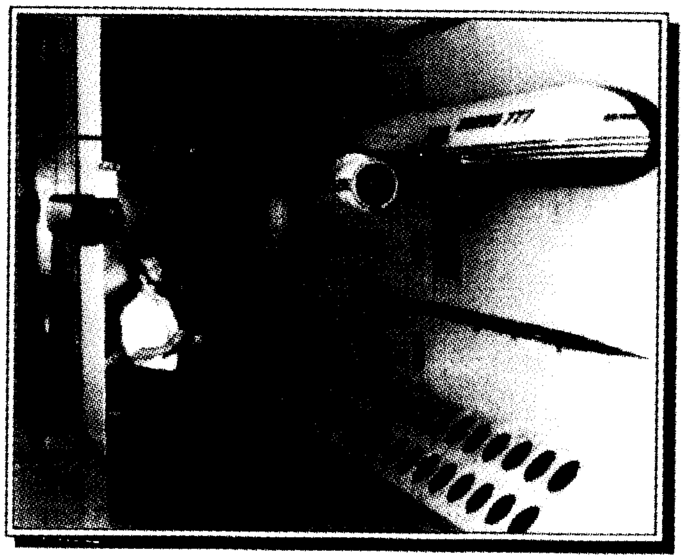
Accomplishment Description: Ten configurations were tested throughout the simulated flight envelope of the aircraft without obtaining flutter. Parameters that were varied included wing fuel, engine pylon stiffness, and the stiffness of the structure that attached the wing to the fuselage. To create a configuration for which flutter would occur thus providing data for assessing the accuracy of analytical flutter prediction methods, a mass was installed in the wing tip. A flutter boundary was obtained for this configuration. The variation of the flutter dynamic pressure with Mach number is shown on the right in the figure. These data show a decrease in flutter dynamic pressure with increasing Mach number. This trend is consistent with what is usually found at high subsonic, low transonic Mach numbers. The experimental data agreed fairly well with preliminary analytical predictions (not shown) for this configuration.

Significance: The experimental flutter data obtained will be used to calibrate analytical flutter codes being used in the flutter safety certification of the 777 airplane. Incidentally, these model tests were the first tests successfully conducted using heavy gas in the TDT following a major CofF to the heavy gas reclamation system.

Future Plans: No additional tests will be required.

Figure 7 (a).

BOEING 777 FLUTTER MODEL TEST COMPLETED IN TDT



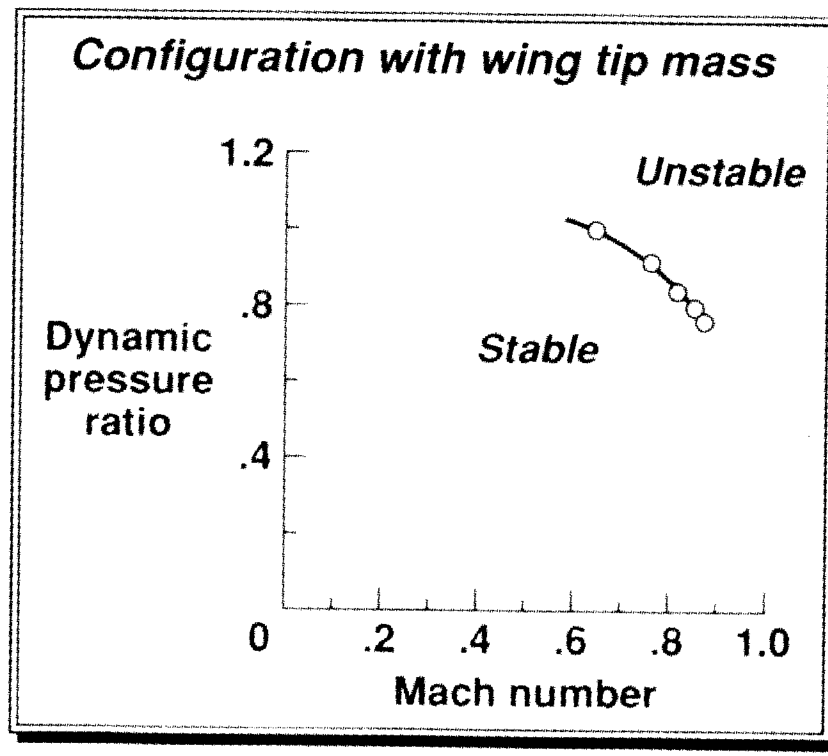


Figure 7 (b).

NASP FLEXIBLE FUSELAGE MODEL READY FOR TESTING IN TDT

Stan Cole
Configuration Aeroelasticity Branch

David L. Soistmann and Charles V. Spain
Lockheed Engineering and Sciences Co.

RTOP 763-23-45

Research Objective: As part of the NASP development program, a wind tunnel test is to be conducted to investigate the subsonic and transonic flutter behavior of a model scaled from a demonstrator version of the NASP vehicle. The objective of the test is to measure the flutter mechanism for this type of vehicle, examine the effect on the flutter behavior through parametric variations of the model, and to correlate the experimental data with analysis.

Approach: The wind tunnel model is a full-span, 1/10 scale representation of an unclassified NASP demonstrator. The fuselage length is fifteen and a half feet and the span from wing tip to wing tip is just under six feet. As may be seen in the figure, the model is to be floor mounted with both pitch and plunge degrees of freedom simulated with springs. The fuselage was constructed to have a high degree of flexibility. A pair of all-movable delta wings is located at the aft end of the fuselage. Through the use of bearings and springs these wings are allowed to pitch and flap. A pair of cantilevered rigid fins is located on the top, aft end of the fuselage. Test plans include mapping flutter boundaries for the following parametric variations: wing pivot spring stiffness, wing pivot location, fuselage thickness, model weight, and model center-of-gravity location.

Accomplishment Description: A wind tunnel model has been constructed and instrumented for testing in the TDT. A floor mount for testing this model was also constructed and includes springs for simulation of both model pitch and plunge degrees of freedom. The floor mount also has an electric actuator for remotely changing the model pitch angle. Analyses of the NASP vehicle and the wind tunnel model have shown the flutter mechanism to be a body freedom type flutter. This flutter mechanism involves a rigid body degree of freedom and model flexible degrees of freedom. The figure shows these three critical modes for the wind tunnel model which are the fuselage rigid pitch mode, the first fuselage bending mode, and the wing pivot mode. The root locus plot shows a decrease in frequency for the first fuselage bending and wing pivot modes as dynamic pressure increases and it shows an increase in frequency for the rigid pitch mode. The three modes couple to produce an aeroelastic instability known as body freedom flutter.

Significance: The experimental data from this test will be directly applicable to the NASP project in terms of the parametric variation studies and the analytical correlation.

Future Plans: Wind tunnel testing of the model is scheduled to begin in November 1992.

Figure 8 (a).

NASP FLEXIBLE FUSELAGE MODEL READY FOR TESTING IN TDT

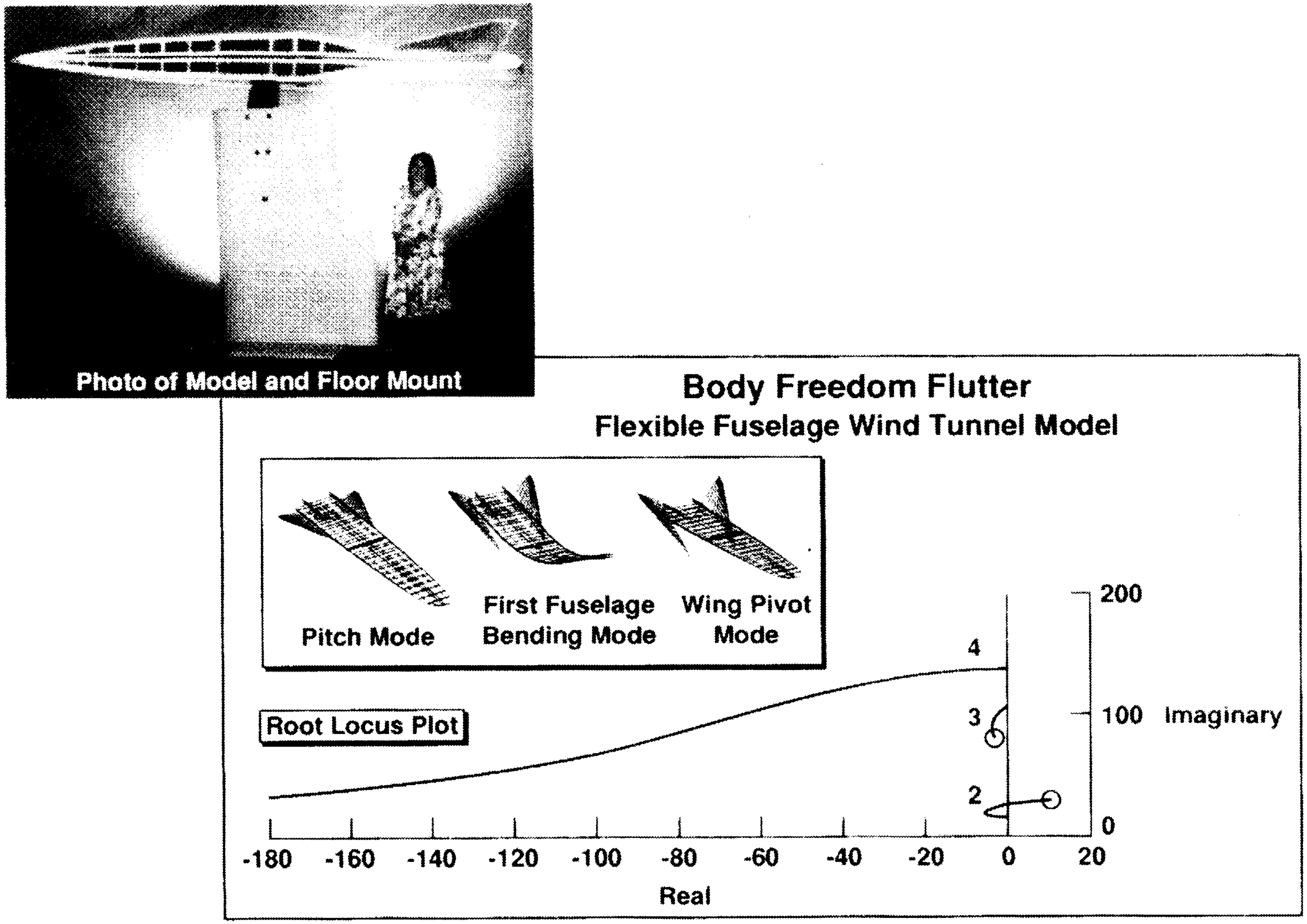


Figure 8 (b).

UNSTEADY PRESSURE DISTRIBUTIONS MEASURED DURING FLUTTER OF BENCHMARK-MODEL-PROGRAM NACA0012 MODEL

José A. Rivera, Jr., Bryan E. Dansberry and Michael H. Durham
Configuration Aeroelasticity Branch

Robert M. Bennett and Walter A. Silva
Unsteady Aerodynamics Branch

RTOP 505-63-50

Research Objective: A Benchmark Models Program (BMP) has been initiated at Langley with a primary objective of obtaining data for aeroelastic computational fluid dynamic (CFD) code development, evaluation, and validation. The first model in the series, a wing with a conventional airfoil supported on a flexible mount system, was tested to define the conventional flutter boundary and measure unsteady surface pressures during flutter.

Approach: A rigid rectangular wing of panel aspect ratio 2.0 with a NACA 0012 airfoil was tested in the Transonic Dynamics Tunnel (TDT) on the flexible Pitch and Plunge Apparatus. A photo of the model mounted in the TDT test section is shown in the accompanying figure. The model was equipped with eighty insitu pressure transducers to measure wing upper and lower surface steady and unsteady pressures. The model and support system were also instrumented with accelerometers and strain gage bridges. A ground vibration test was performed to define the wind-off structural dynamic characteristics of the model system. Wind-on data were obtained in the Mach number range from 0.3 through 0.97.

Accomplishment Description: During the wind-tunnel test data were gathered for CFD code development, evaluation and validation. Wing upper and lower surface steady and unsteady pressures were measured at the conventional flutter boundary (coupling of pitch and plunge modes) for the model at zero-degrees angle-of-attack along chordlines at the 60 and 95 percent span stations. A discrete Fourier analysis, at the flutter frequency, was used to determine the magnitude and phase of the oscillating pressures during flutter. The magnitudes of the pressures, Cp', were normalized by the magnitude of the oscillating pitch angle, and the phase angles were calculated relative to the pitch motion (a phase angle is positive when a pressure transducer oscillatory signal leads the wing pitch motion). Cp' and Phase plots are shown in the lower portion of the figure for M= 0.67, 0.77, 0.82. Data are presented on the left for the 60 percent span station and on the right for the 95 percent span station. Only the upper surface Cp' and phase values are presented (the upper and lower surface measurements were in very good agreement and indicated the same trends as expected for a symmetric airfoil at zero degrees angle of attack). The effect of the shock on the unsteady pressure distribution as Mach number increases to M=0.82 is shown in the figure.

Significance: The availability of a comprehensive data set defining model structural dynamic characteristics and measured model instability boundaries such as flutter along with associated steady and unsteady pressure measurements is expected to be a useful tool for the development, evaluation, and validation of CFD methods.

Future Plans: Data reduction is ongoing. Final results will be documented in a series of formal publications. A third test is planned in which the model will be tested in a heavy gas to gather data at higher Reynolds numbers.

Figure 9 (a).

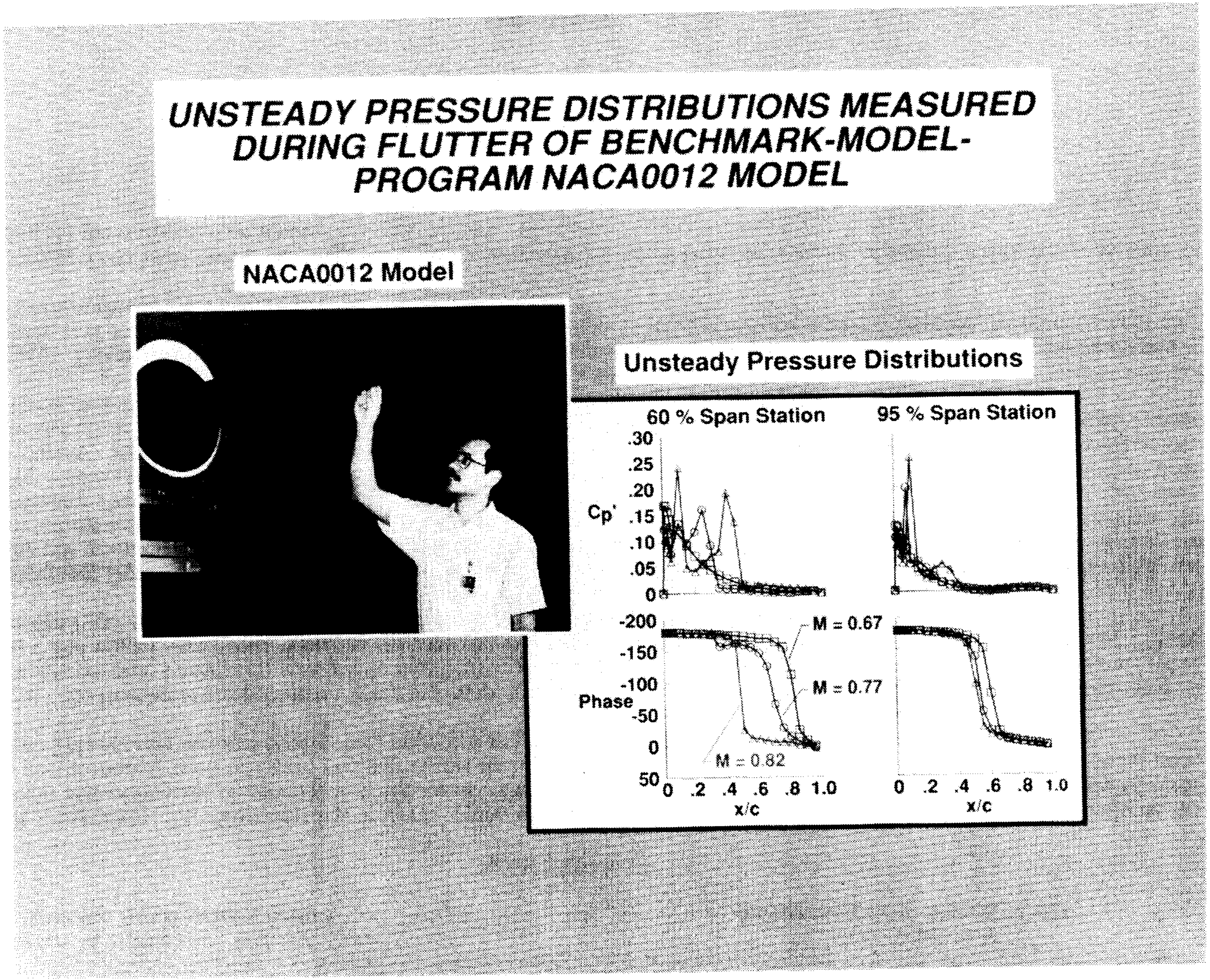

UNSTEADY PRESSURE DISTRIBUTIONS MEASURED DURING FLUTTER OF BENCHMARK-MODEL-PROGRAM NACA0012 MODEL
NACA0012 Model
Unsteady Pressure Distributions
60 % Span Station
95 % Span Station
Cp'
.30
.25
.20
.15
.10
.05
0
-200
-150
-100
-50
0
50
Phase
M = 0.67
M = 0.77
M = 0.82
0 .2 .4 .6 .8 1.0
x/c

Figure 9 (b).

UNSTEADY PRESSURES ACQUIRED DURING FLUTTER ON THE BENCHMARK SUPERCRITICAL WING

Bryan E. Dansberry, José A. Rivera, and Michael H. Durham
Configuration Aeroelasticity Branch

David L. Turnock
Lockheed Engineering & Sciences Company

Robert M. Bennett and Walter A Silva
Unsteady Aerodynamics Branch

Carol D. Wieseman
Aeroservoelasticity Branch, SDyD

RTOP 505-63-50

Research Objective: The Structural Dynamics Division of LaRC initiated the Benchmark Models Program to facilitate the development and evaluation of aeroelastic CFD codes. The Benchmark Supercritical Wing Model is one of a family of three different airfoil models used to create comprehensive and complimentary experimental data sets suitable for analytical code correlation. This data set includes both surface pressures and model response information.

Approach: The Benchmark Supercritical Wing is a rigid, half-span wing with a simple rectangular planform. It is instrumented with 80 in-situ pressure transducers arranged to provided upper and lower surface pressure distributions at two span stations (60% and 95%). The model was flutter tested in the Transonic Dynamics Tunnel while mounted on the flexible Pitch and Plunge Apparatus (PAPA). Accelerometers and strain-gauge bridges were located on the model and PAPA mount.

Accomplishment Description: Data were acquired at flutter conditions for a Mach number range of 0.3 to .97 using both air and R-12 as the test medium. Several stall flutter points were recorded for model angles of attack greater than five degrees. The upper right corner of the figure shows the experimentally defined flutter boundary for model angle-of-attack of zero. Also shown are the surface pressure characteristics recorded during the flutter point corresponding to a Mach number of 0.74. These data were derived from 20 continuous seconds of measurements at the instability point. The model motion is illustrated by the two time histories shown. Mean, minimum, and maximum values of the oscillating pressure measurements are shown as well as the magnitude and phase (referenced to model pitch motion) of the unsteady portion. The pressure data shown are for the 60% span station. These data are available for all instability points encountered during wind-on testing

Significance: The availability of a comprehensive data set defining structural dynamic characteristics, wind-on model response (flutter) data, and associated unsteady surface pressure distributions is expected to be a useful tool for the development and evaluation of aeroelastic CFD methods.

Future Plans: Data reduction is in progress. Final results will be documented in a series of formal publications as well as presentations to the aerospace community.

Figure 10 (a).

UNSTEADY PRESSURES MEASURED DURING FLUTTER OF BENCHMARK SUPERCRITICAL WING

MODEL MOUNTED IN TDT

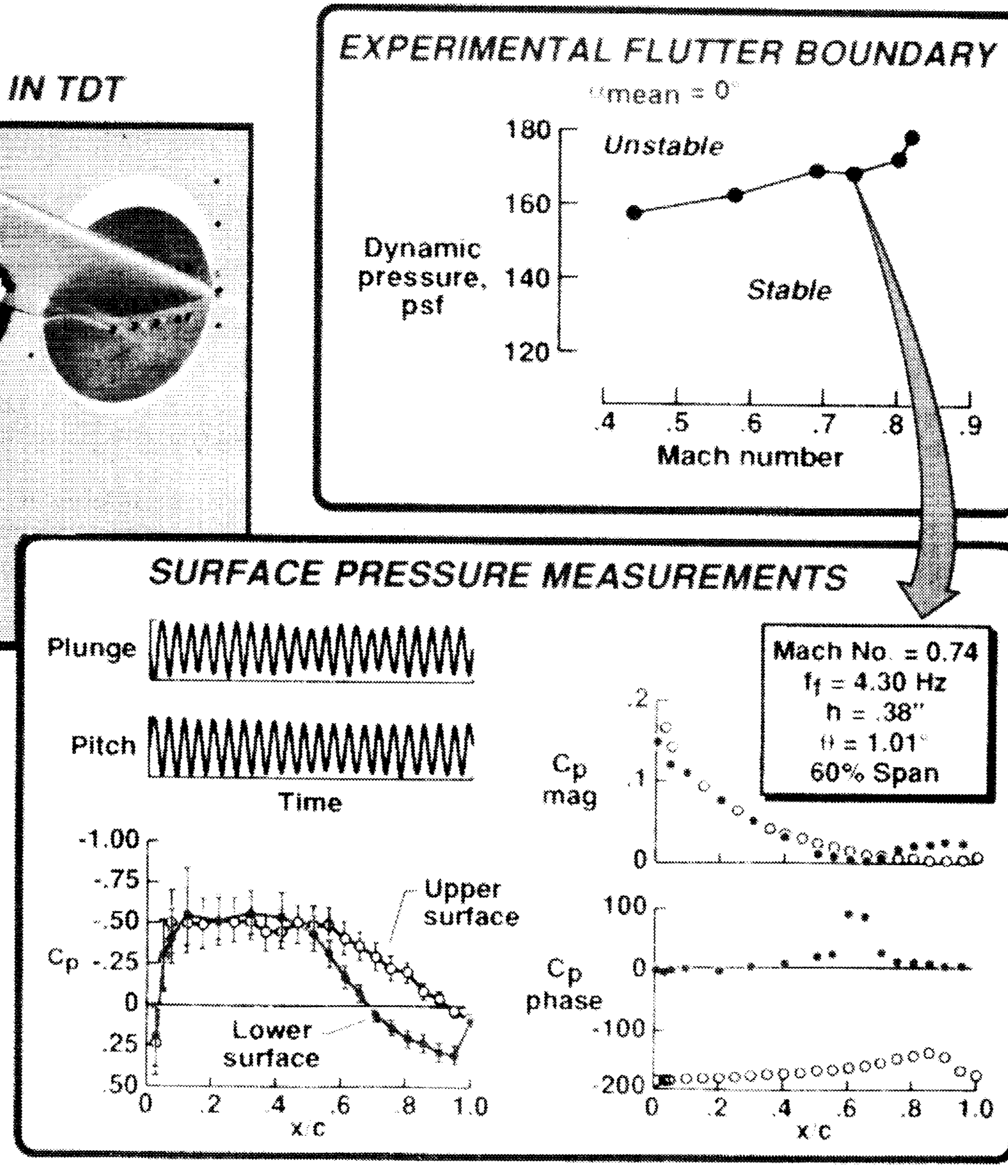


Figure 10 (b).

FLUTTER AND FLOW CHARACTERISTICS OF AN EXPLORATORY HSCT MODEL DETERMINED IN TDT

Michael H. Durham & Lee B. Thomason
Configuration Aeroelasticity Branch

David L. Turnock
Lockheed Engineering & Sciences Co.

RTOP 505-63-50

Research Objective: A Benchmark Models Program has been initiated at NASA Langley with the objective of obtaining experimental data for aeroelastic computational fluid dynamic code development and validation. Two models in this program are 1/12 scale semi-span wings of a generic High Speed Civil Transport (HSCT). The first model is essentially rigid and will be tested on a flexible mount system that provides two rigid-body degrees of freedom. The second model is a dynamically scaled aeroelastic model. Both models will be instrumented with pressure transducers and will be tested up to and during flutter. Due to model design constraints and the desire for wing-tip instrumentation, the wing thickness of these models must be greater than the proposed full scale HSCT. There are concerns that this increased airfoil thickness may cause separated flow at relatively low angles-of-attack. The objectives of this test were to determine the aeroelastic characteristics of a rigid HSCT planform on the flexible mount system and to determine critical parameters for the design and test of the instrumented rigid model.

Approach: An approximately 1/50 scale HSCT planform wing was fabricated from aluminum and structural foam. The foam was worked into an airfoil section representative of a HSCT but with a constant 4% thickness from root to tip. The rigid model was tested on the flexible mount in the TDT as shown in figure. The mount was instrumented with strain gages and accelerometers for measurement of model frequencies, displacements, and forces. A ground vibration test was performed to define the wind-off structural characteristics. Wind-on data were obtained in the Mach number range from 0.35 to 1.00. Tufts were mounted on the model to determine the flow patterns at various model angles-of-attack.

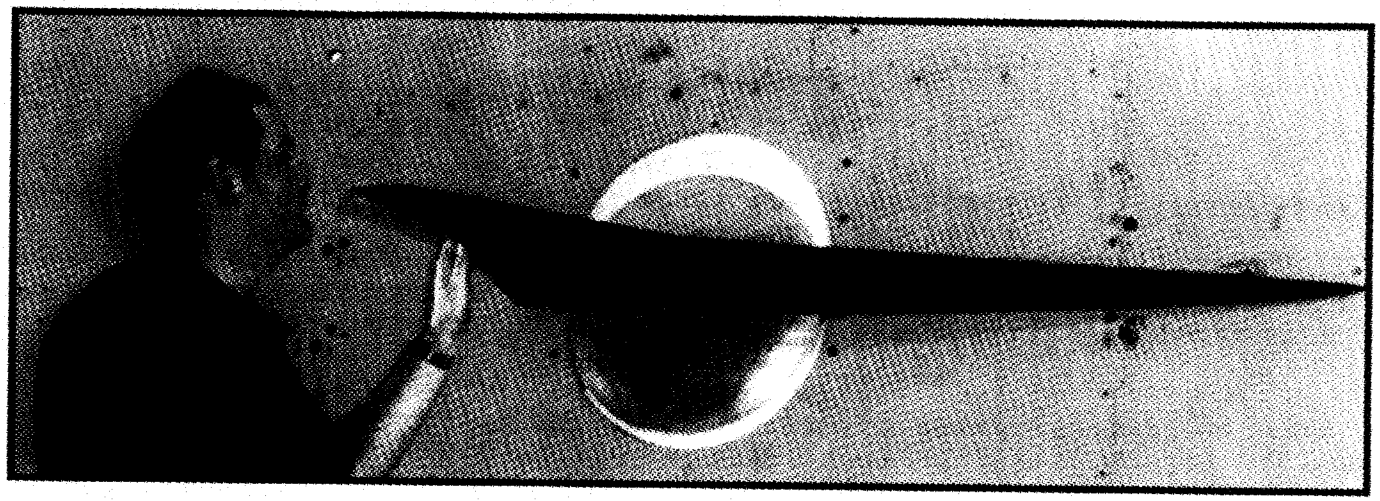
Accomplishment Description: A flutter boundary was measured for various Mach numbers and correlated with an analysis using kernel function aerodynamics. Good correlation was observed as seen in the attached figure. Flow patterns were observed on the tufts at angles-of-attack from $^{-}2°$ to $^{+}4.5°$ as shown in the figure. At angles-of-attack less than $^{+}2°$, the flow did not exhibit signs of separation. At angles above $^{+}2°$, there was separation which grew with increased Mach number.

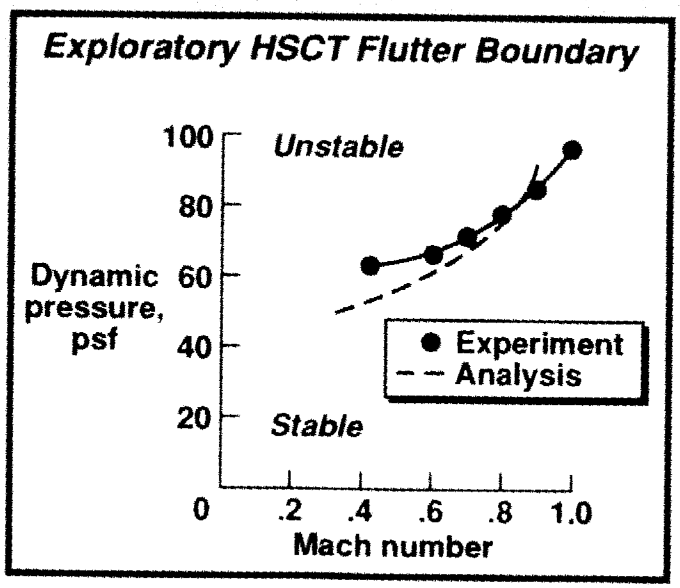
Significance: The correlation of the flutter boundary between analyses and tests indicates that an HSCT model of this type tested on a flexible mount is a viable experiment, and that plans for the future instrumented rigid model should proceed. The flow patterns indicate that separation should not be a concern at low angles-of-attack.

Future Plans: Design and analyses of the 1/12 scale models are proceeding. Wind-tunnel tests of these larger scale pressure instrumented models are scheduled to begin in early 1994.

Figure 11 (a).

FLUTTER AND FLOW CHARACTERISTICS OF AN EXPLORATORY HSCT MODEL DETERMINED IN TDT





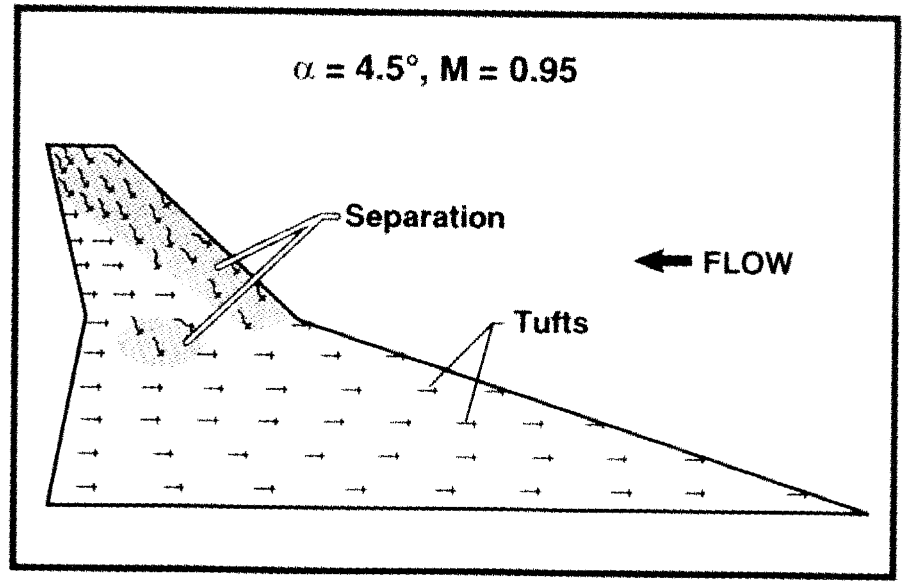


Figure 11 (b).

TDT TESTS CONDUCTED TO EVALUATE BRITISH ROTOR BLADE TECHNOLOGY

William T. Yeager, Jr., Configuration Aeroelasticity Branch

Kevin W. Noonan, U. S. Army Vehicle Structures Directorate

Paul H. Mirick, Jeffrey D. Singleton, Matthew L. Wilbur
Configuration Aeroelasticity Branch

505-63-36

Research Objective: In the fall of 1986, a Westland Helicopters Ltd. Lynx, equipped with paddle-type main rotor blades developed under the British Experimental Rotor Program BERP), claimed the Class E-1 (helicopters without payload) speed record. Westland has claimed that the BERP rotor blades can provide either an increase in aircraft speed for a constant thrust or an increase in load factor for a constant aircraft speed. A limited flight evaluation by U.S. Army personnel confirmed that in comparison to standard blades, the BERP blades did provide a significant increase in aircraft speed at high thrust coefficients and a reduction in vibration levels at speeds above 60 knots. A test has been conducted in the Langley Transonic Dynamics Tunnel (TDT) to acquire data to allow evaluation of a BERP-type aeroelastically scaled model rotor blade.

Approach: A test was conducted in the TDT using baseline and BERP-type model rotor blades mounted on a four-bladed articulated hub. The baseline and BERP-type blades used the same RC-series airfoils, the same radial distribution of airfoils, the same radial twist distribution, and had the same thrust-weighted solidity. Both sets of blades were tested on the Aeroelastic Rotor Experimental System (ARES) testbed.

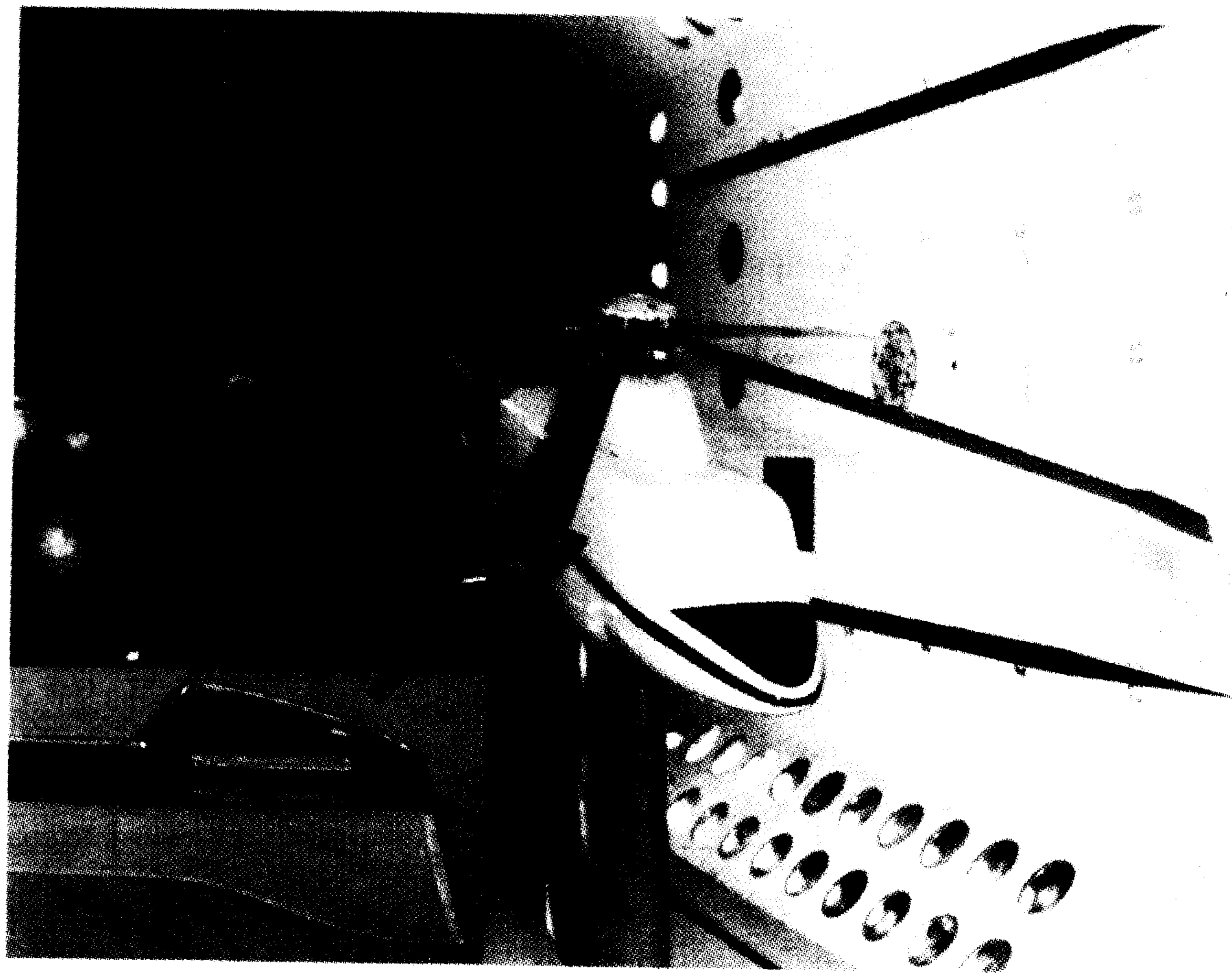
Accomplishment Description: A large data base has been acquired to allow evaluation of the BERP-type planform. Rotor performance and fixed-system vibratory loads data were acquired for each blade set over a range of rotor lift coefficients, rotor drag coefficients, and advance ratios. Data analysis is currently under way.

Significance: Because the next generation of U.S. Army helicopters will be required to be fast, maneuverable, and to carry increased payloads, the successful performance of the BERP blades makes it imperative that the BERP technology be evaluated as a possible enhancement to current U.S. industry rotor design methods.

Future plans: Future plans call for the completion of the data analysis and documentation in a NASA formal report.

Figure 12 (a).

TDT TESTS CONDUCTED TO EVALUATE BRITISH ROTOR BLADE TECHNOLOGY



BBH-1 Yeager

Figure 12 (b).

TDT TESTS CONDUCTED TO EVALUATE LANGLEY-DESIGNED SLOTTED AIRFOILS FOR USE ON HELICOPTER ROTORS

Matthew L. Wilbur
Configuration Aeroelasticity Branch

Kevin W. Noonan
U. S. Army Vehicle Structures Directorate

505-63-36

Research Objective: Aerodynamicists have long recognized the compromises that must be made in designing airfoils for use on helicopter rotors. The camber line and thickness distribution that are desirable for attaining high maximum lift coefficients are in nearly direct opposition to those desirable for attaining high drag divergence Mach numbers and low pitching moment coefficients. Significant improvements in maximum lift coefficients compared to those of existing rotorcraft airfoils, especially for tip airfoil sections which require the highest drag divergence Mach numbers, may not be possible unless unconventional designs are considered. Therefore, the design of slotted airfoils was initiated by U.S. Army personnel at Langley Research Center. Tests to evaluate the slotted airfoil concept have been conducted in the Langley Transonic Dynamics Tunnel (TDT).

Approach: A test was conducted in the TDT using aeroelastically scaled model rotor blades mounted on a four-bladed articulated rotor. The tests involved a baseline configuration as well as three configurations incorporating either fixed leading or trailing edge slots over the outboard 20% of the blade span. The tests were conducted using the Aeroelastic Rotor Experimental System (ARES) testbed.

Accomplishment Description: A large data base has been acquired to allow evaluation of the slotted airfoil concept. Rotor performance and fixed-system vibratory loads were acquired over a range of rotor lift coefficients, drag coefficients, and advance ratios. Data analysis is currently underway.

Significance: Increased maneuverability and agility, as well as increased lift capability, will be requirements for future U.S. Army and civil rotorcraft. The slotted airfoil concept may be one means of providing the necessary rotor lifting capability without incurring additional penalties in the rotor power requirements.

Future Plans: Future plans call for the completion of the data analysis and documentation in a NASA formal report. Additionally, a study is under way to investigate means of azimuthally varying the blade trailing edge flap angle to determine the effect of this parameter on rotor performance and fixed-system vibratory loads.

Figure 13 (a).

TDT TESTS CONDUCTED TO EVALUATE LANGLEY-DESIGNED SLOTTED AIRFOILS FOR USE ON HELICOPTER ROTORS

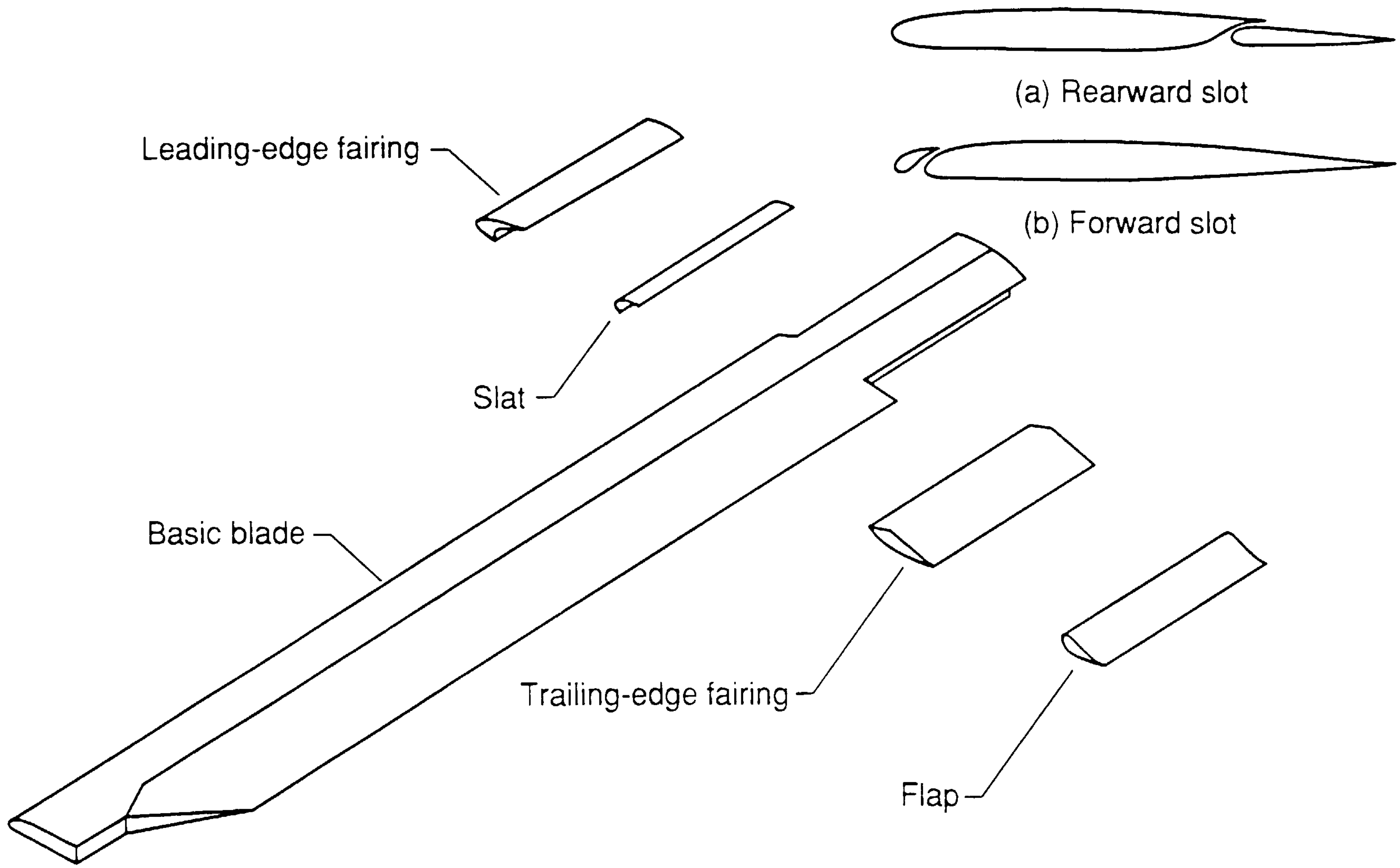


Figure 13 (b).

MODIFICATIONS COMPLETED FOR THE TRANSONIC DYNAMICS TUNNEL HEAVY GAS RECLAMATION SYSTEM

Bryce M. Kepley
Configuration Aeroelasticity Branch

RTOP 505-63-50

Research Objective: The objective of this project is to improve the heavy gas recovery system at the Transonic Dynamics Tunnel (TDT) to reduce heavy gas losses to an acceptable level. Reaching this goal will allow the TDT to resume normal operations as a highly functional test facility using heavy gas as the test medium.

Approach: Historically, the TDT has used heavy gas, namely dichlorodifloromethane (R-12), as the test medium for approximately 95% of test operations since the early 1960's. Heavy gas is approximately four times heavier than air and has a speed of sound about half that of air. This is a significant advantage for testing aeroelastic models at transonic speeds because it allows use of heavier models, requires less tunnel fan horsepower, and provides higher Reynolds number test conditions. The modified heavy gas reclamation system includes a Low Temperature Condenser (LTC) system which is supplied with liquid nitrogen (LN2) from a new dewar, a two-tower gas dryer, a regeneration system for an existing air dryer, controls and instrumentation. New valves have been installed with a scavenging technique to capture any leakage from the stems and flanges. Structural pockets in the plenum have either been ported or filled with cellular glass insulation to eliminate heavy gas entrapment during the removal process.

Accomplishment Description: The urgency of this project was the result of the Agency's concern and sensitivity to the loss of R-12 into the environment; hence, since July 1989 this project has been designed, funded, and completed. The design required that all equipment be compatible with a future alternate gas. During the system checkout a hydrate having a composition of R-12 and moisture was formed in the cold box of the LTC system thereby causing a detrimental blockage in the system. Hence, a second cold box capable of handling larger solids was placed into service to permit the operation of the first cold box at a warmer temperature to reduce the possibility of forming a hydrate. Initial plans were to utilize the second cold box to process a future alternate gas. An Operational Readiness Review was held September 2, 1992 and the TDT was declared operationally ready for both air and heavy gas operations.

Significance: TDT operations in the heavy gas mode are needed to support critical model tests which cannot be accomplished in an air medium. Further enhancements to the heavy gas reclamation system will continue.

Future Plans: A study will be implemented immediately to investigate alternate gas candidates that may be used in the TDT because R-12 will become unavailable in the near future. Two present examples being considered are R-134A and SF6(Sulfurhexacloride).

Figure 14 (a).

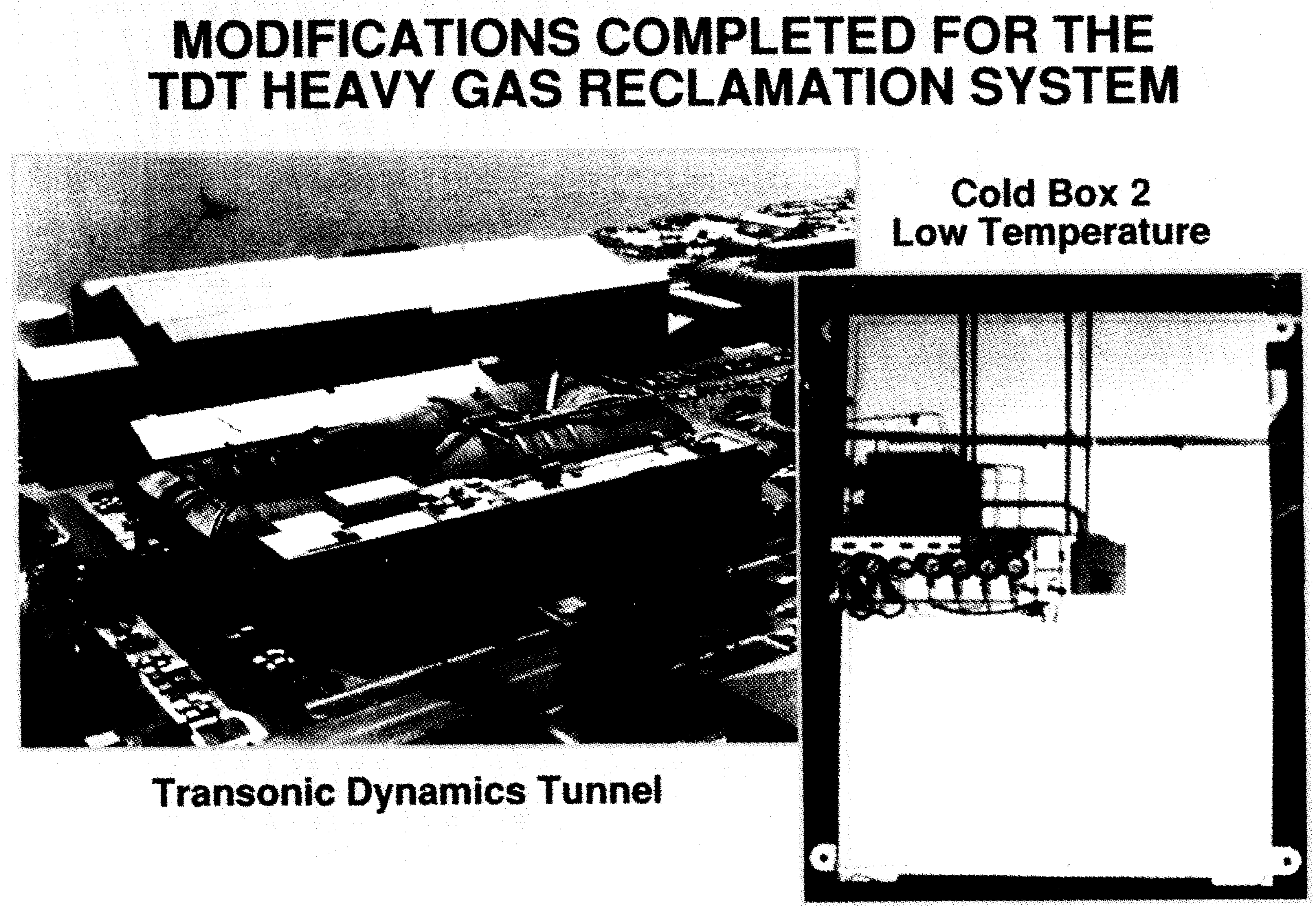

MODIFICATIONS COMPLETED FOR THE
TDT HEAVY GAS RECLAMATION SYSTEM
Cold Box 2
Low Temperature
Transonic Dynamics Tunnel

Figure 14 (b).

HARDWARE IMPROVEMENTS TO TRANSONIC DYNAMIC TUNNEL DATA ACQUISITION SYSTEM

David C. Rosser, Jr.
Configuration Aeroelasticity Branch

RTOP 505-63-21

Objective:- Wind-tunnel testing of aeroelastic models requires the acquisition of voluminous amounts of data from a variety of different sensors. Near real time analysis of selected data channels is required to provide test engineers with information needed to guide testing. The sophisticated computer-controlled Data Acquisition System (DAS) at the Langley Transonic Dynamics Tunnel (TDT) was designed to satisfy these requirements. Because of the evolutionary changes in aeroelastic test requirements, upgrading system hardware components is continually required to better meet current and future research needs.

Approach - Previous operational experiences and projected research needs were carefully assessed to determine a prioritized lists of needed DAS improvements. Two items from this lists were selected for implementation. These improvements are modifications to the disc storage capacity and upgrading the computer central processing units.

Accomplishment Description - The first improvement consists of replacing six of the canister-type, individually controlled disc drives with two larger disc drives that operate under a single controller. Even though there are fewer new discs the storage capacity is increased by a factor of two. Furthermore, the new UNIX-based discs are faster than the units they replaced so input-output operations are faster. In addition, the new discs are more compatible with other units so that data are easily transportable to other systems. The second improvement consists of replacing the existing three computer central processing units (CPU). These units are shown at the left in the figure. Two of the CPUs were replaced with units that are four times faster. The third CPU was replaced with a unit that is two times faster. The new CPUs, which occupy the signal cabinet shown on the right in the figure, provide an increase in central memory from 8 megabytes to 16 megabytes. The larger and faster CPUs provide a means for acquiring 256 channels of in-phase data at frequencies up to 1000 Hertz. The new hardware components are currently being checkout out. A special switching systems has been developed which will allow for the new equipment to be checkout satisfactorily before the replaced equipment is discarded.

Significance - These hardware additions will provided significant improvements to the operational efficiency of the TDT data acquisition system by providing more data storage capacity, faster data analysis and more display capabilities, thus improving data quality and providing for more efficient wind-on testing.

Future Plans - Following final checkout, the new hardware items will be permanently incorporated into the TDT DAS. In addition, system capability needs will be assessed continuously and system improvements will be made as warranted.

Figure 15 (a).

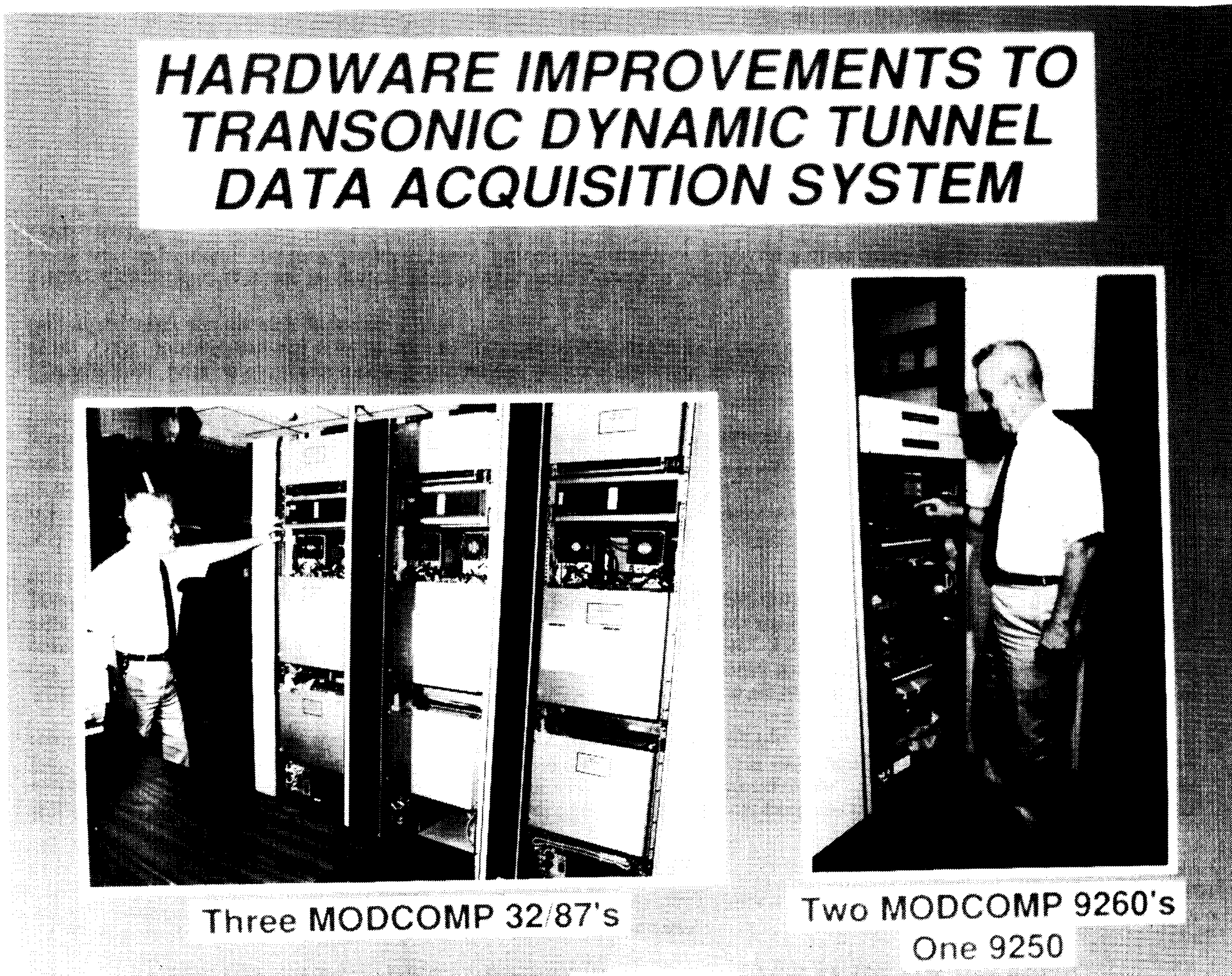

HARDWARE IMPROVEMENTS TO
TRANSONIC DYNAMIC TUNNEL
DATA ACQUISITION SYSTEM
Three MODCOMP 32/87's
Two MODCOMP 9260's
One 9250

Figure 15 (b).

VIDEO DYNAMIC DEFORMATION MEASUREMENT SYSTEM READY FOR USE IN TDT

Bryan E. Dansberry
Configuration Aeroelasticity Branch

RTOP 505-63-50

Research Objective: The Transonic Dynamics Tunnel (TDT) is used almost exclusively for aeroelastic research. Data sets currently acquired in the TDT do not include static or dynamic model deformations. The purpose of the Video Dynamic Deformation Measurement System (VDDMS) is to take a first step toward measuring model deformations by allowing researchers to measure the deflections in the vertical direction of a model wing tip.

Approach: The VDDMS uses a black and white CCD camera placed so that the optical axis of the camera is perpendicular to the 1 dimensional motion to be measured. Targets are placed on the model wing tip. These targets are colored to give maximum contrast on a black and white image and sized as large as possible. Video images are recorded on Super VHS for later data reduction. These images are downloaded onto an analog optical disk and processed through an Androx frame grabber board on a Sun workstation. The targets are tracked in pixel space and deflections of each target tracked are presented in engineering units for each field of video reduced.

Accomplishment Description: The VDDMS was used to measure tip deflections of a transport wing model recently tested in the Transonic Dynamics Tunnel. Data were acquired for peak to peak tip motions of up to 1.5 inches. A photo of the wing tip of this model is shown in the figure. Black targets on a white background were used to give maximum contrast. These targets are circular and approximately 3/8 in diameter. The plot shows the time history of one of the targets during a period of 10 seconds. These data were recorded while the model was undergoing buffet response at a Mach number equal to 0.96 and a dynamic pressure of 44 psf.

Significance: Data on the actual model deformations during testing will significantly increase the value of data sets acquired in the TDT. Researchers will now be able to correlate analytical flutter results based on measured deformations as well as flutter frequency and dynamic pressure.

Future Plans: Plans include laboratory tests to determine system accuracy and the variables which affect this accuracy (i.e. target size, target color, and focal length of lens). Further data reduction software will be developed to graphically display the system results.

Figure 16 (a).

VIDEO DYNAMIC DEFORMATION MEASUREMENT SYSTEM READY FOR USE IN TDT

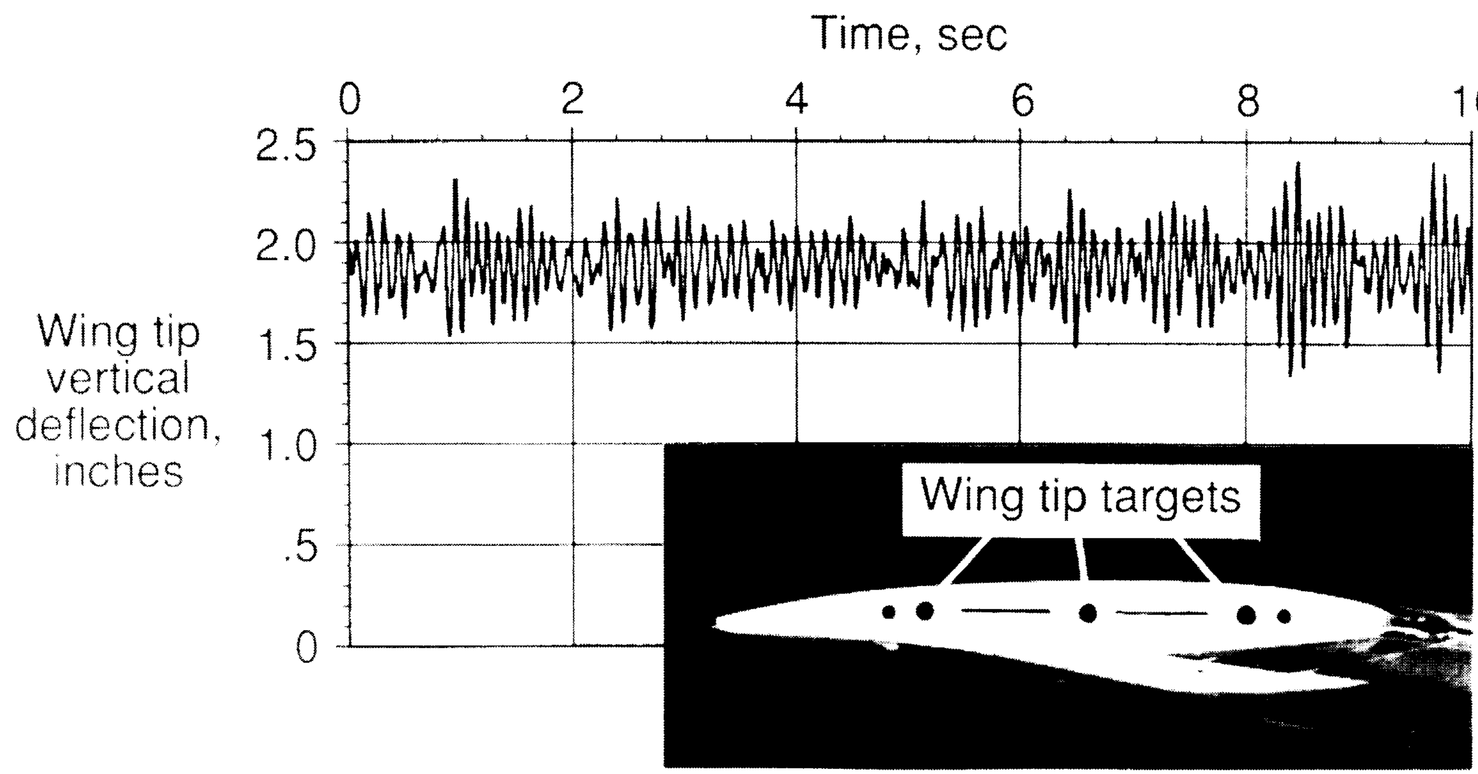


Figure 16 (b).

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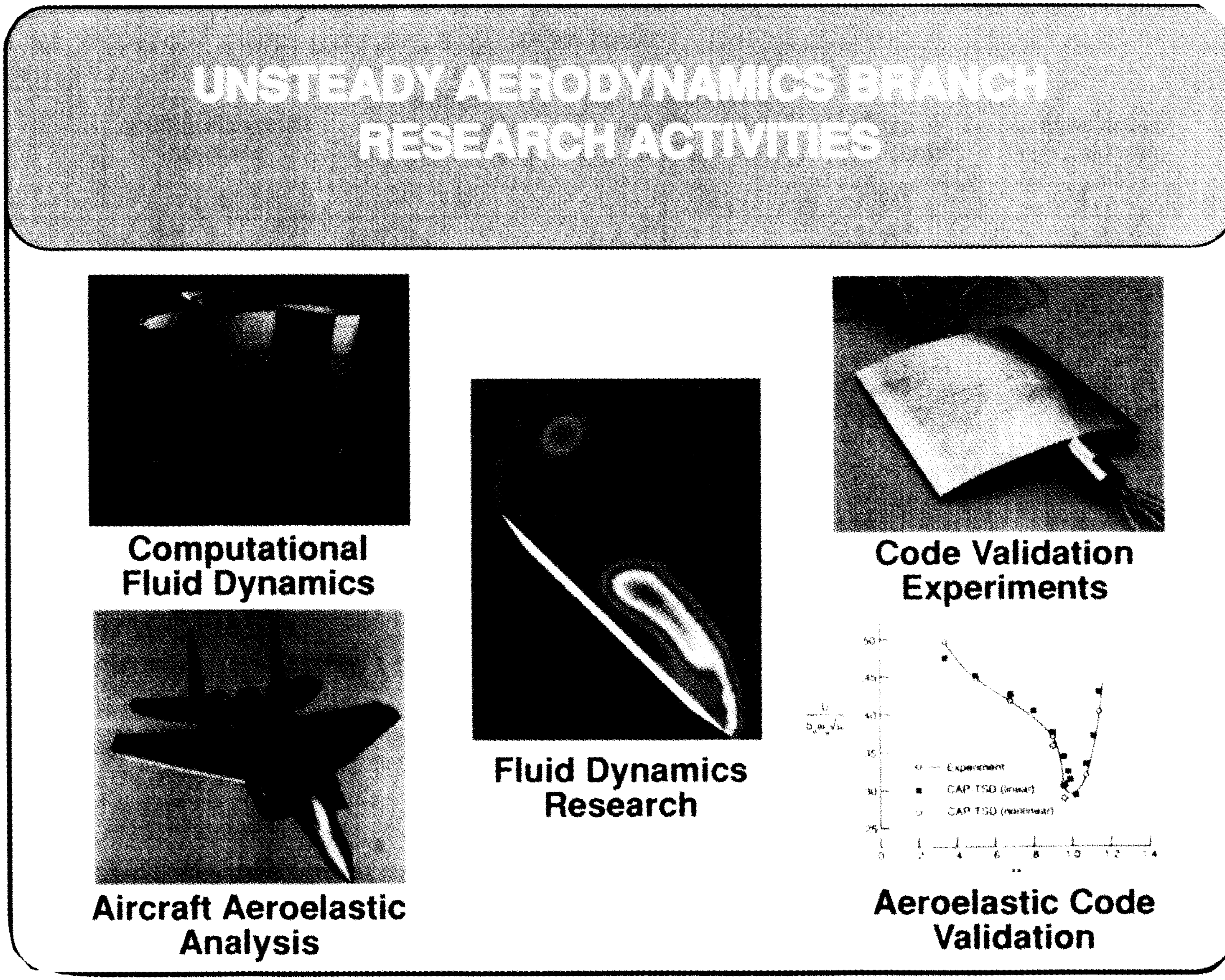

Figure 17.

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UNSTEADY AERODYNAMICS
FUTURE PLANS (FY 93-97)

GOAL

DEVELOP, VALIDATE, AND APPLY UNSTRUCTURED-GRID AND GRIDLESS EULER/NAVIER-STOKES CODES FOR AIRCRAFT AEROELASTIC ANALYSIS

KEY OBJECTIVES

- CONTINUED CODE DEVELOPMENT

FY 93	FY 94	FY 95	FY 96	FY 97
3D Laminar Navier-Stokes Eqs.	3D Turbulent Navier-Stokes Eqs.	3D Navier-Stokes Eqs. Aeroelastic Code	Advanced Turbulence Modeling	N.S. Aeroel. Code on Parallel Computers

- CODE APPLICATIONS

FY 93	FY 94	FY 95	FY 96	FY 97
3D Euler Wing/Body Flutter	N.S. Wing Flutter And Separated Flow	N.S. Wing/Fuselage Flutter And Separated Flow	Wing-Store LCO	N.S. Twin-Tail Fighter Buffet

Figure 18 (a).

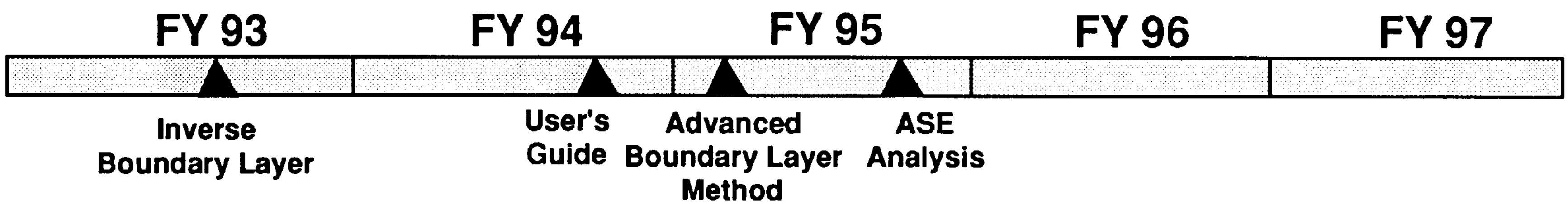
UNSTEADY AERODYNAMICS FUTURE PLANS (FY 93-97)

GOAL

COMPLETE DEVELOPMENT OF, VALIDATE, AND APPLY TSD CODE FOR AIRCRAFT AEROELASTIC ANALYSIS

KEY OBJECTIVES

- CAP-TSD CODE MODIFICATIONS



- CAP-TSD APPLICATIONS

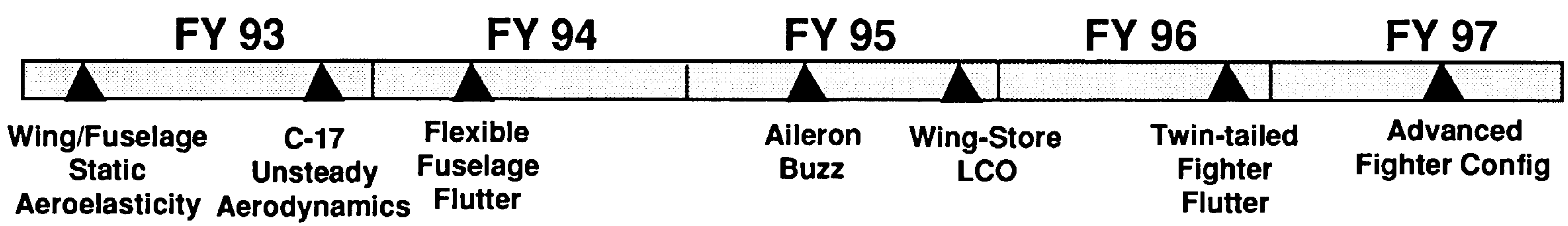


Figure 18 (b).

UNSTEADY AERODYNAMICS
FUTURE PLANS (FY 93-97)

GOAL

SUPPORT DEVELOPMENT OF EXPERIMENTAL DATA BASES FOR VALIDATION OF AERODYNAMIC / AEROELASTIC CFD CODES

KEY OBJECTIVES

- BENCHMARK MODELS

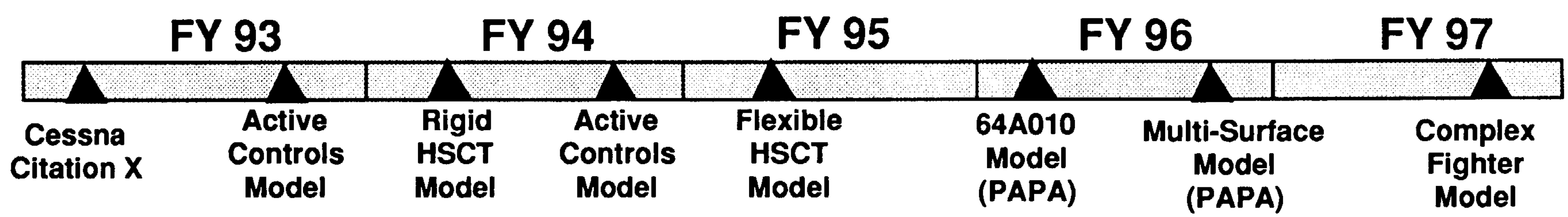


Figure 18 (c).

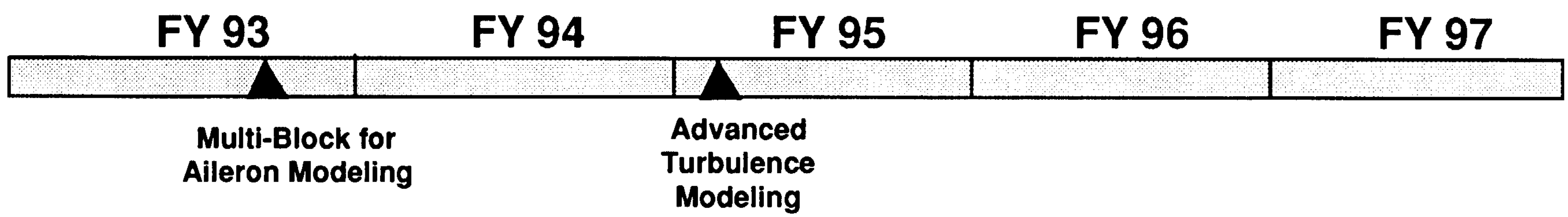
UNSTEADY AERODYNAMICS FUTURE PLANS (FY 93-97)

GOAL

DEVELOP, VALIDATE, AND APPLY STRUCTURED-GRID, EULER/ NAVIER-STOKES CODES FOR AIRCRAFT AEROELASTIC ANALYSIS

KEY OBJECTIVES

- CODE EXTENSIONS



- CODE APPLICATIONS

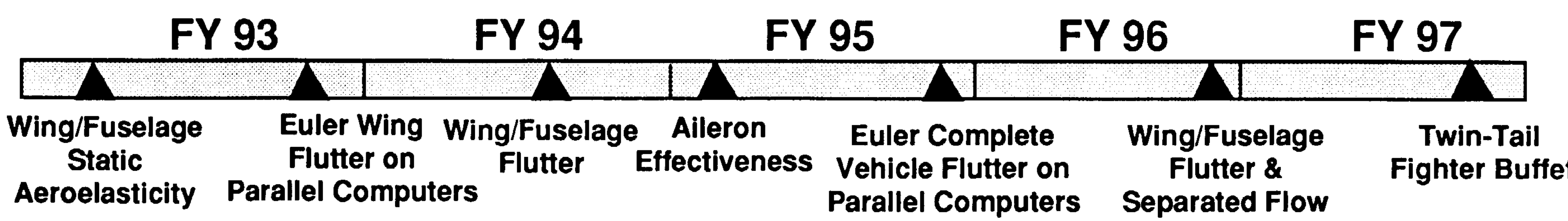


Figure 18 (d).

SYMMETRIC AND ANTISYMMETRIC FLUTTER BOUNDARIES PREDICTED FOR THE AFW WIND-TUNNEL MODEL

Walter A. Silva and Robert M. Bennett
Unsteady Aerodynamics Branch

RTOP 505-63-50

Research Objectives: There were two objectives for the present work. The first objective was to compute a symmetric flutter boundary of the Active Flexible Wing (AFW) wind-tunnel model (upper left of figure) using the CAP-TSD (Computational Aeroelasticity Program-Transonic Small Disturbance) code. The second objective was to evaluate, for the first time, the capability of the code to compute an antisymmetric flutter boundary and, in particular, to compute the antisymmetric flutter boundary of the AFW wind-tunnel model.

Approach: Two computational models of the AFW wind-tunnel model were generated. A semi-span model that included the first ten symmetric modes was used for computation of the symmetric flutter boundary. A full-span model (upper right of figure) that included the first ten symmetric modes in addition to the first ten antisymmetric modes was used for computation of the antisymmetric flutter boundary. The symmetric modes were needed in the antisymmetric model for computation of the static aeroelastic deformation that is needed prior to flutter analyses. Both computational models were the result of significant model refinements.

Accomplishment Description: A comparison of flutter boundaries (Mach number versus dynamic pressure), for symmetric and antisymmetric motions of the AFW wind-tunnel model, is shown at the lower part of the figure for the improved computational models and for the experimental data. Comparison of the symmetric data shows excellent agreement between the computed and experimental results at transonic Mach numbers. The computed antisymmetric flutter boundary shown in the figure is believed to be the first antisymmetric flutter boundary computed using an aeroelastic CFD (Computational Fluid Dynamics) code and thereby validates the antisymmetric flutter capability of the CAP-TSD code. The comparison at subsonic Mach numbers needs improvement and is believed to be caused by additional refinements that are required for the accurate modeling of the wing tip ballast stores. However, it is important to note that the crossing of the symmetric and antisymmetric flutter boundaries predicted by CAP-TSD is consistent with the experimental data.

Significance: The study clearly demonstrates that accurate computational symmetric and antisymmetric transonic flutter predictions using the CAP-TSD code are possible. The study also validates, for the first time, the capability of the CAP-TSD code to perform antisymmetric flutter analyses.

Future Plans: Analyses using an additional enhancement to the modeling of the wing tip ballast stores will be performed when that capability becomes available. The discrepancy between the computational and experimental flutter results at subsonic conditions will then be investigated using these enhancements. Viscous effects also will be investigated when the viscous version of the CAP-TSD code is operational.

Figure 19 (a).

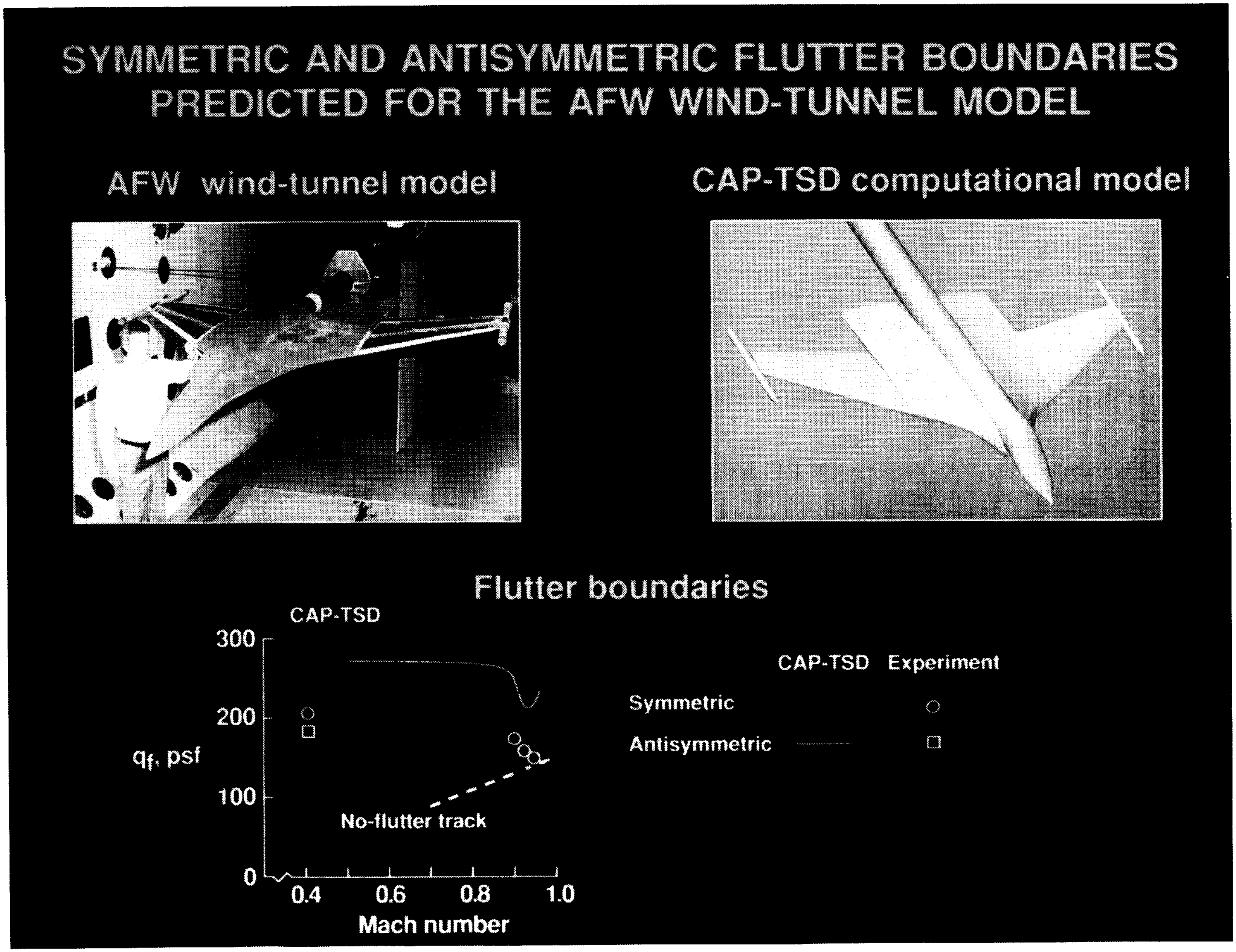

SYMMETRIC AND ANTISYMMETRIC FLUTTER BOUNDARIES
PREDICTED FOR THE AFW WIND-TUNNEL MODEL
AFW wind-tunnel model
CAP-TSD computational model
Flutter boundaries
CAP-TSD
q_f, psf
300
200
100
0
0.4
0.6
0.8
1.0
Mach number
No-flutter track
CAP-TSD
Experiment
Symmetric
Antisymmetric

Figure 19 (b).

TRANSONIC SHOCK OSCILLATIONS CALCULATED WITH A NEW INTERACTING BOUNDARY LAYER COUPLING METHOD

John W. Edwards
Unsteady Aerodynamics Branch

RTOP 505-63-50

Research Objective: The objective of this research is to develop a robust and efficient method for computing transonic aeroelastic responses that are characterized by separated flows that frequently can be naturally unsteady and involve oscillations of a shock/boundary layer system with a characteristic frequency.

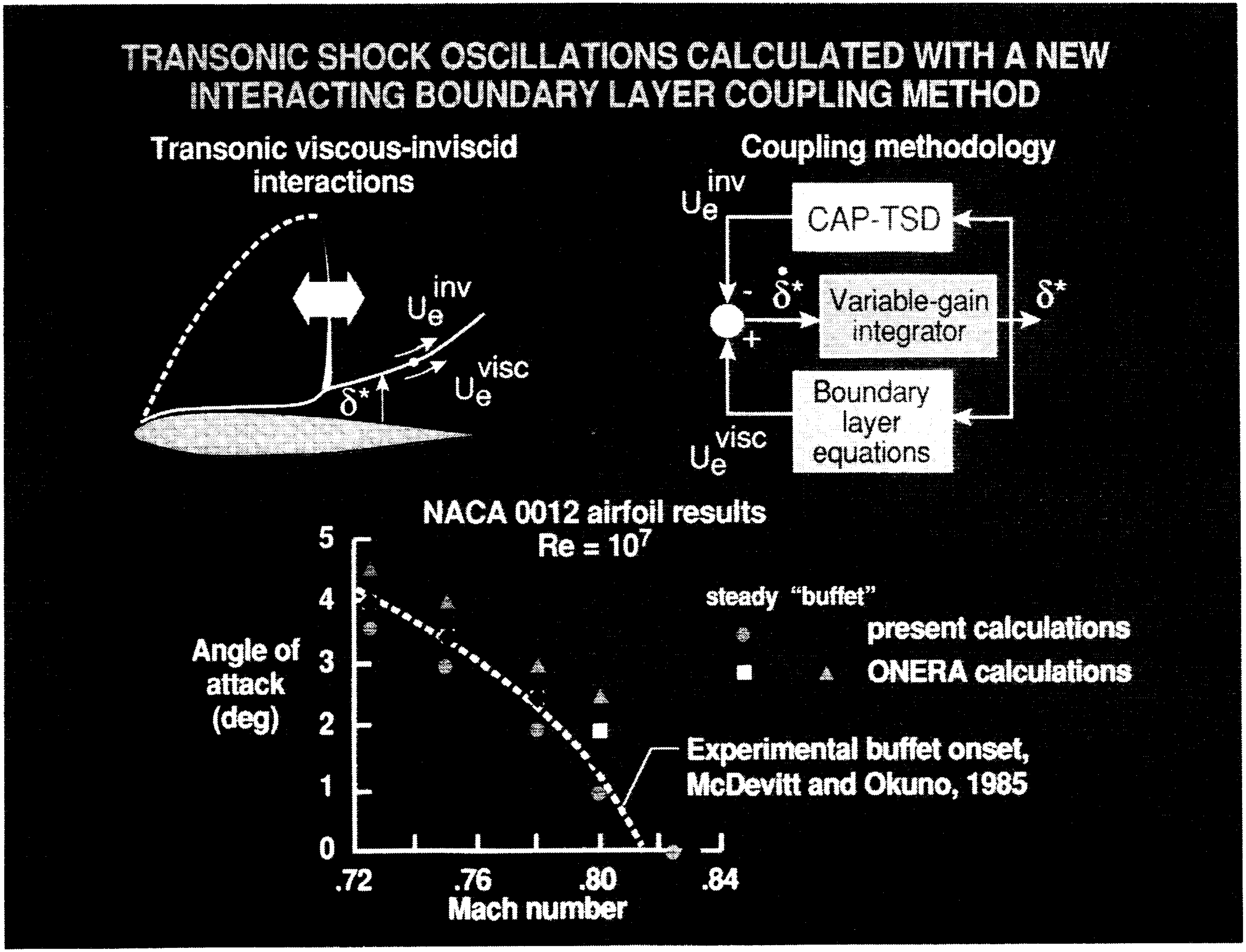
Approach: At high subsonic Mach numbers, a region of supersonic flow terminated by a shock wave develops over the airfoil (upper left figure). The viscous boundary layer adjacent to the airfoil grows in thickness from the leading edge to the trailing edge. Interacting Boundary-Layer Theory (IBLT), which has been very successful for attached flow cases, solves two flow models--one for the outer-inviscid flow including the shock wave, and one for the thin viscous boundary layer region--maintaining consistency by requiring the matching of inviscid and viscous velocities, U_e^{inv} and U_e^{visc}, at the edge of the boundary layer. For attached flows, U_e^{inv} can be used to obtain a direct solution of the Boundary Layer Equations (BLE) for the required displacement thickness, d^*. However, when flow separation is encountered, the BLE become singular and much effort has been given to inverse solution procedures. This requires an iterative solution for U_e^{visc}, given U_e^{inv} and an assumed $d^*(x)$. The problem thus becomes one of developing a coupling method (upper right figure) for iteratively updating $d^*(x)$, such that the error $U_e^{visc} - U_e^{inv}$ is minimized. For the cases of most interest, this must be accomplished such that self-excited shock oscillations are accurately captured.

Accomplishment Description: A new coupling method has been developed, using the inviscid CAP-TSD (Computational Aeroelasticity Program-Transonic Small Disturbance) code and an inverse integral BLE model, which allows calculations of unsteady separated transonic flows. The IBLT is regarded as a simulation of two dynamic systems whose coupling requires active control elements to minimize the coupling error. The key element utilized is a variable gain integrator for calculating $d^*(x)$. The bottom figure shows the excellent agreement with the experimental buffet onset boundary for the NACA 0012 airfoil at a Reynolds number of 10 million. These results are an improvement over those of ONERA researchers who used a similar IBLT flow model but a different coupling method. These flow oscillations involve shock motions over 25 percent of the chord at approximately 40 Hz (1 ft. chord).

Significance: The new coupling method allows the robust and efficient computation of a range of flow conditions which have previously been very difficult and/or very expensive to compute: separation bubbles, shock-induced or trailing-edge separated flows, and unsteady separating/reattaching flows. This capability can be expected to provide improved accuracy for transonic flutter boundary computations.

Future Plans: The new coupling method will be incorporated within the CAP-TSD code in a two-dimensional strip fashion, allowing flutter boundary computations for wings with separated flow. Computations will be made for aeroelastic wings whose flutter mechanisms show strong evidence of interaction with self-excited shock oscillations (e.g., the DAST ARW-2 wing).

Figure 20 (a).



TRANSONIC SHOCK OSCILLATIONS CALCULATED WITH A NEW INTERACTING BOUNDARY LAYER COUPLING METHOD
Transonic viscous-inviscid interactions
U_e^{inv}
U_e^{visc}
δ^*
Coupling methodology
CAP-TSD
Variable-gain integrator
Boundary layer equations
$\dot{\delta}^*$
δ^*
NACA 0012 airfoil results
Re = 10^7
Angle of attack (deg)
Mach number
steady "buffet"
present calculations
ONERA calculations
Experimental buffet onset, McDevitt and Okuno, 1985

Figure 20 (b).

FLEXIBLE SWEPT VERTICAL SURFACE CAPABILITY ADDED TO CAP-TSD AEROELASTICITY CODE

John T. Batina
Unsteady Aerodynamics Branch

Michael D. Gibbons
Lockheed Engineering & Sciences Company

RTOP 505-63-50

Research Objective: The objective of this research is to develop the capability to allow nonlinear aeroelastic calculations on configurations which include swept flexible vertical surfaces.

Approach: The CAP-TSD (Computational Aeroelasticity Program - Transonic Small Disturbance) code could previously model rigid rectangular vertical surfaces. To extend CAP-TSD to treat flexible vertical surfaces of arbitrary planform extensive modifications were necessary. The major modifications include 1) the addition of terms to the TSD potential equation to account for swept shocks on the vertical surfaces, 2) devising a method to shear the grid vertically so that it conforms to the planform of the vertical surface, and 3) adding structural flexibility by computing the generalized aerodynamic forces and including in the structural equations of motion.

Accomplishment Description: The modifications necessary to treat general vertical surface configurations have been made to CAP-TSD. To demonstrate the accuracy of the modifications calculations were performed on an AGARD T-Tail configuration shown in the accompanying figure. The results were computed using a mesh of medium density with a view of the surface mesh shown in the lower left of the figure. The jump in surface pressure coefficients are shown for a fin twist mode shape at $M = 0.8$ near the midspan of the vertical fin. The fin twist mode shape has zero twist at the root of the vertical fin with the twist increasing linearly in the spanwise direction. The unsteady results were computed by harmonically oscillating the vertical fin in twist for several cycles of motion. In order to compare the CAP-TSD results with linear theory the linear equation coefficients were used. Comparisons show that for both the steady and unsteady cases CAP-TSD is in excellent agreement with linear theory.

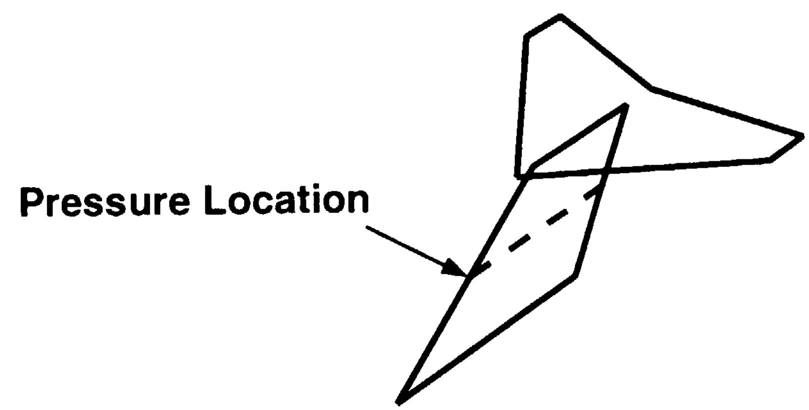
Significance: The ability to model flexible vertical surfaces with CAP-TSD allows for nonlinear aeroelastic studies to be conducted on more general configurations.

Future Plans: Further test cases are planned to validate fully the vertical surface modifications for nonlinear aeroelastic applications pending the official release of these modifications.

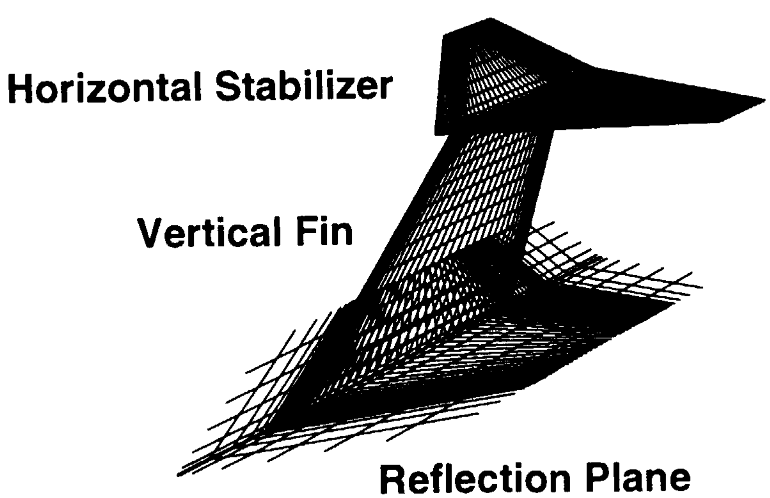
Figure 21 (a).

FLEXIBLE SWEPT VERTICAL SURFACE CAPABILITY ADDED TO CAP-TSD AEROELASTICITY CODE

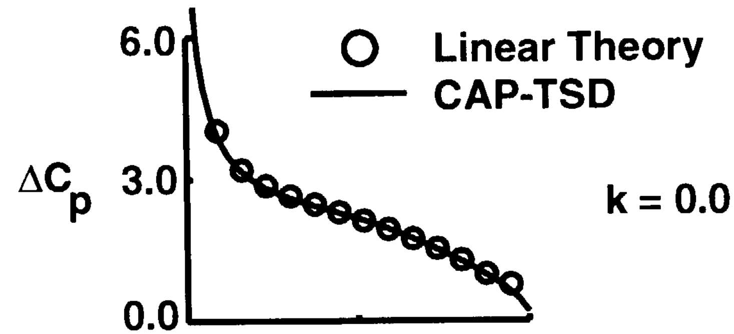
AGARD T-Tail Configuration



Surface Gridding



Fin Twist M = 0.8



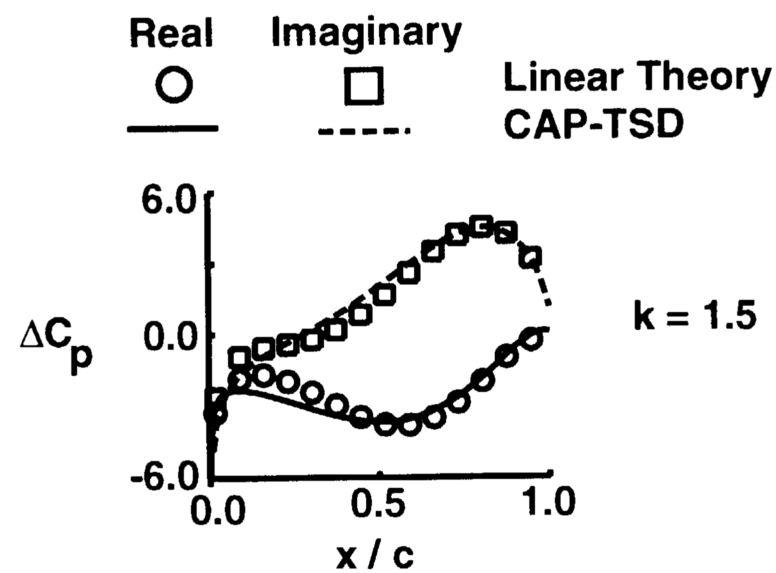


Figure 21 (b).

SUBSONIC/TRANSONIC FLUTTER BOUNDARY COMPUTED USING UNSTEADY EULER AERODYNAMIC METHOD

Elizabeth M. Lee-Rausch
Unsteady Aerodynamics Branch

RTOP 505-63-50

Research Objective: The objective of this research is to continue the evaluation of the aeroelastic version of the CFL3D Euler/Navier-Stokes code for wing flutter predictions.

Approach: The configuration studied in the first AGARD standard aeroelastic configuration for dynamic response was tested in the Transonic Dynamics Tunnel (TDT). This wing has a quarter-chord sweep angle of 45°, a panel aspect ratio of 1.65, a taper ratio of 0.66, and a NACA 65A004 constant airfoil section. A photograph of the model mounted in the TDT is shown in the upper left figure. Flutter data for this model tested in air is reported over a range of freestream Mach numbers from 0.338 to 1.141. The flutter speed index versus Mach number for this model exhibits the characteristic transonic "bucket" or dip near Mach one.

Accomplishment Description: The aeroelastic version of CFL3D in the Euler mode was used to compute a complete flutter boundary for the 45° swept-back wing. A partial view of the computational mesh modeling the wing surface and the symmetry plane is shown in the lower left figure. Flutter analyses were performed at freestream Mach numbers of 0.338, 0.678, 0.90, 0.96, 1.07, and 1.14. The results of these analyses are compared to the experimentally determined flutter speed index and flutter frequency ratio in the upper right and lower right figures, respectively. These figures show that at subsonic freestream Mach numbers the computed flutter speed index agrees well with the experimental value while the computed frequency ratio is slightly below the experimental value. As the freestream Mach number approaches one, the computed flutter speed index is slightly below the experimental values, and the frequency ratio agrees well with the experimental value. For Mach numbers greater than one where the flutter boundary is particularly sensitive to Mach number, the computed boundary indicates a sharper rise than the experimental boundary.

Significance: The good agreement between the computed and experimental values of flutter speed index and frequency ratio for the 45° swept-back wing at freestream Mach numbers below one tends to validate the unsteady Euler aerodynamic method for subsonic and transonic Mach numbers. Also, these results are believed to be one of the first three-dimensional flutter boundary calculations for a wing obtained using the Euler equations.

Future Plans: Differences in the predicted flutter speeds for supersonic freestream Mach numbers will be investigated using aeroelastic analysis based on the Navier-Stokes equations.

Figure 22 (a).

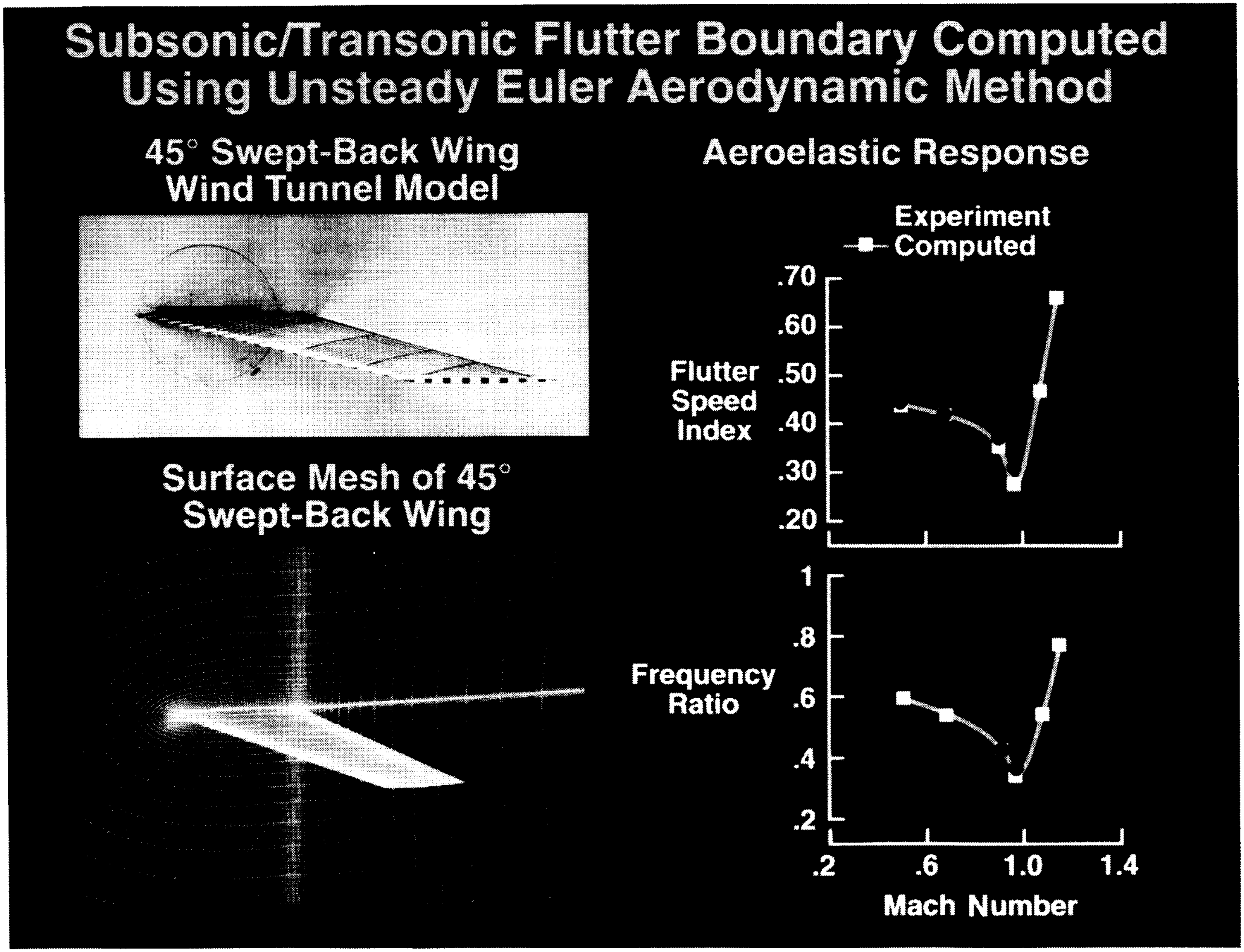

Subsonic/Transonic Flutter Boundary Computed Using Unsteady Euler Aerodynamic Method
45° Swept-Back Wing Wind Tunnel Model
Surface Mesh of 45° Swept-Back Wing
Aeroelastic Response
Experiment
Computed
Flutter Speed Index
.70
.60
.50
.40
.30
.20
Frequency Ratio
1
.8
.6
.4
.2
.2
.6
1.0
1.4
Mach Number

Figure 22 (b).

TWO-DIMENSIONAL GRIDLESS EULER/NAVIER-STOKES SOLUTION ALGORITHM DEVELOPED

John T. Batina
Unsteady Aerodynamics Branch

RTOP 505-63-50

Research Objective: Historically, computational fluid dynamics (CFD) methods have been developed for the solution of the Euler and Navier-Stokes equations based on either structured or unstructured grids. Use of either type of grid has inherent disadvantages due to grid topology, as well as advantages and, consequently, no method has emerged as a clearly superior choice. Therefore, the objective of the research was to determine if an algorithm could be developed to solve the governing flow equations that does not use a grid, and thus obviate the choice of grid topology.

Approach: A method was developed that uses only clouds of points and does not require that the points be connected to form a grid as is necessary in conventional CFD algorithms. The governing partial differential equations (PDEs) are solved directly, by performing local least-squares curve fits in each cloud of points, and then analytically differentiating the resulting curve-fit equations to approximate the derivatives of the PDEs. The method is neither a finite-difference nor a finite-volume type approach since differences, metrics, lengths, areas, or volumes are not computed.

Accomplishment Description: Results first were obtained by solving the Euler equations for a transonic flow about the NACA 0012 airfoil. The field of points that was used to model the flow is shown in the upper left part of the figure. A close up view of the points near the nose of the airfoil is shown in the upper right part of the figure. Also shown are ghost points that are located inside of the airfoil to impose the surface boundary conditions. The computational domain has a total of 6,500 points, 134 of which are ghost points. The lower left part of the figure shows Euler pressures computed at $M_\infty = 0.8$ and a = 1.25∞. Here, the generally accepted Euler solution has been obtained and the shock waves are sharply captured. The lower right part of the figure shows Navier-Stokes pressures (obtained using a more dense field of points) computed at $M_\infty = 0.5$, a = 0∞, and Re = 5000. Like the Euler result, this pressure distribution indicates that the generally accepted Navier-Stokes solution involving separated flow near the trailing edge has been obtained.

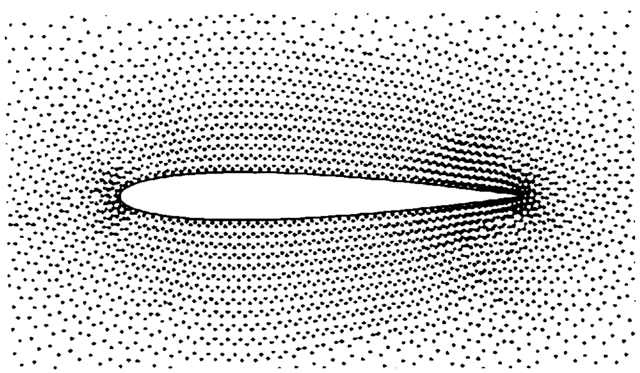
Significance: The gridless CFD approach is feasible and therefore has the potential to resolve the problems and inefficiencies encountered with structured or unstructured grid methods. Consequently, it offers the greatest potential for accurately and efficiently solving viscous flows about complex aircraft configurations.

Future Plans: The three-dimensional version of the gridless algorithm for the solution of the Euler and Navier-Stokes equations is currently under development.

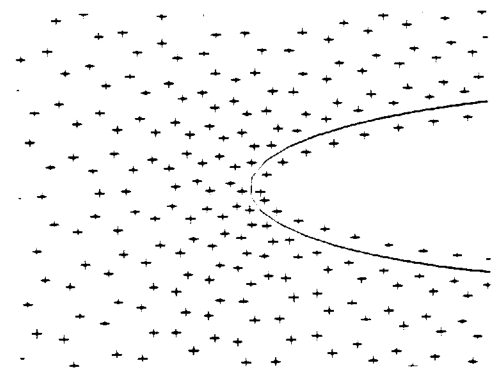
Figure 23 (a).

TWO-DIMENSIONAL GRIDLESS EULER/NAVIER STOKES SOLUTION ALGORITHM DEVELOPED

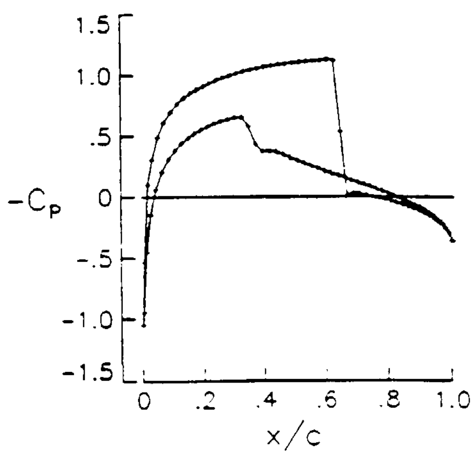
- Field of points about NACA 0012 airfoil



- Close-up view of field of points near airfoil nose



- Euler pressures at $M_\infty = 0.8$ and $\alpha = 1.25°$



- Navier-Stokes pressures at $M_\infty = 0.5$, $\alpha = 0°$, Re = 5000

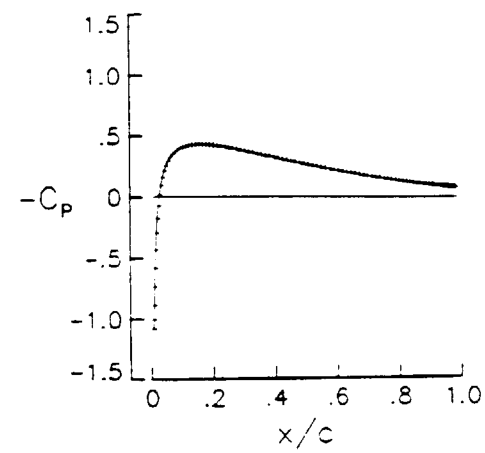


Figure 23 (b).

THREE-DIMENSIONAL, UNSTRUCTURED-GRID EULER METHOD USED FOR TIME-MARCHING AEROELASTIC ANALYSIS

Russ D. Rausch
Purdue University

John T. Batina
Unsteady Aerodynamics Branch

RTOP 505-63-50

Research Objective: The objective of the research is to develop a time-marching aeroelastic analysis method that uses Euler equation aerodynamics for three-dimensional configurations.

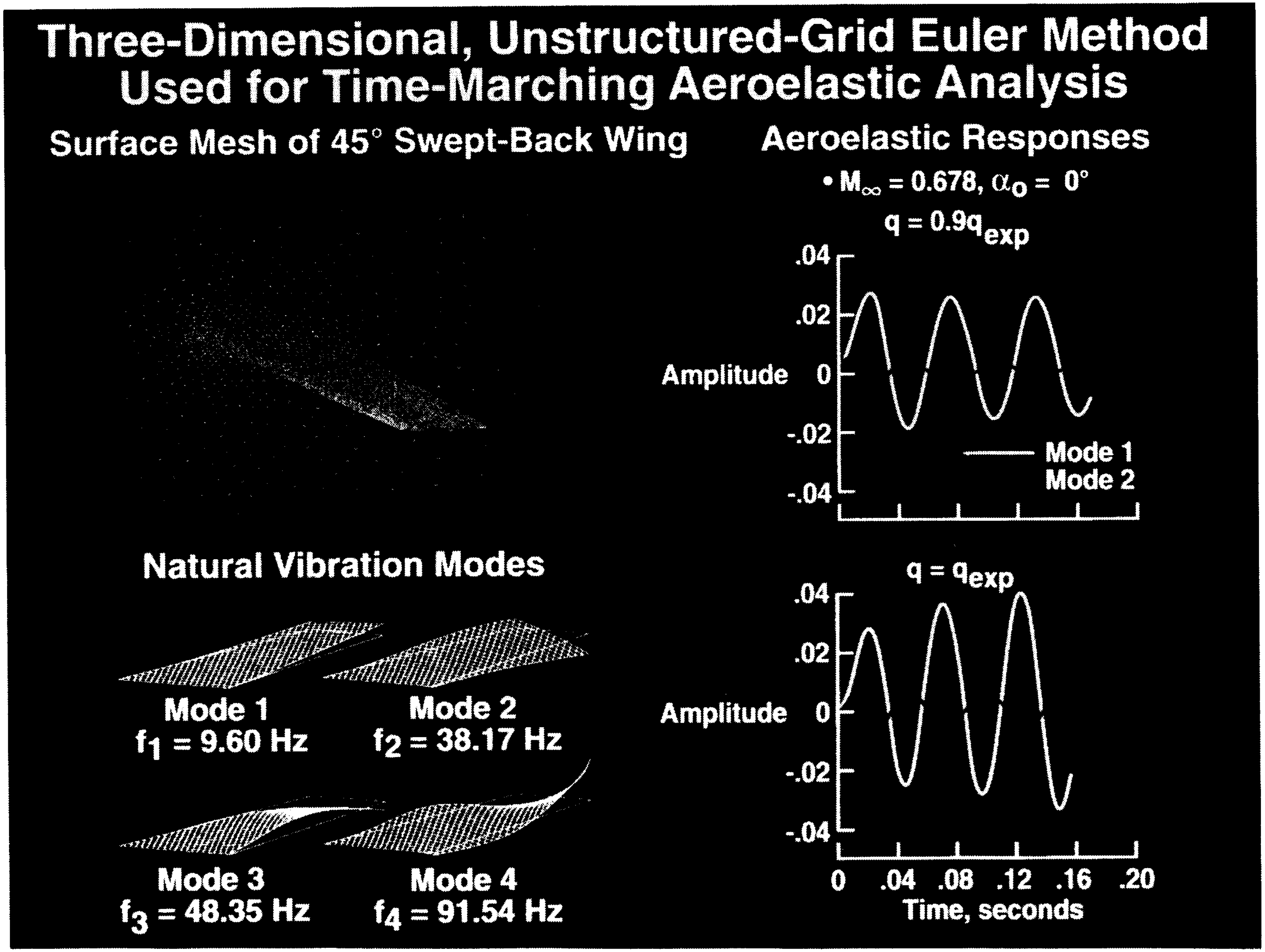
Approach: A novel aspect of the method is that the analysis was performed using unstructured grids made up of tetrahedra that allow the analysis of complex three-dimensional configurations. The structural dynamic equations of motion were incorporated into a three-dimensional, unstructured-grid, upwind Euler code. To perform an aeroelastic analysis, a steady solution was calculated and used to determine the static aeroelastic deformations. The structure then was given an initial excitation, and the structural equations and unsteady Euler equations were integrated in time simultaneously for a given value of dynamic pressure q. The aeroelastic transients were analyzed to determine if the amplitude of the motion increased (unstable) or decreased (stable) with time. When seeking a flutter point in subsequent analyses, the dynamic pressure either was increased, if the motion was stable, or was decreased, if the motion was unstable.

Accomplishment Description: Flutter analysis was performed for a 45° swept-back wing and compared wind tunnel results. The left part of the figure shows a partial view of the surface mesh and the natural vibration modes used in the analysis. An aeroelastic time-marching calculation was performed for a freestream Mach number M_∞ of 0.678 and zero degrees mean angle of attack α_0. The responses then were analyzed for their damping and frequency components to determine their respective flutter characteristics. Aeroelastic responses of the first two structural modes are shown in the right part of the figure for dynamic pressure q equal to nine-tenths of the experimental flutter dynamic pressure q_{exp} and for $q = q_{exp}$. The aeroelastic response is stable for $q = 0.9q_{exp}$ and is clearly unstable for $q = q_{exp}$, as indicated by the increasing amplitude with time of the computed responses.

Significance: The results are the first three-dimensional flutter calculations obtained using the unstructured-grid Euler equation methodology for three-dimensional configurations.

Future Plans: Plans are to develop a highly accurate and efficient solution algorithm for the Euler and Navier-Stokes equations for aeroelastic analysis of complex aircraft configurations.

Figure 24 (a).



Three-Dimensional, Unstructured-Grid Euler Method
Used for Time-Marching Aeroelastic Analysis
Surface Mesh of 45° Swept-Back Wing
Aeroelastic Responses
• $M_\infty = 0.678$, $\alpha_o = 0°$
$q = 0.9q_{exp}$
Amplitude
.04
.02
0
-.02
-.04
Mode 1
Mode 2
$q = q_{exp}$
0
.04
.08
.12
.16
.20
Time, seconds
Natural Vibration Modes
Mode 1
$f_1 = 9.60$ Hz
Mode 2
$f_2 = 38.17$ Hz
Mode 3
$f_3 = 48.35$ Hz
Mode 4
$f_4 = 91.54$ Hz

Figure 24 (b).

EULER FLUTTER ANALYSIS OF A COMPLEX AIRCRAFT CONFIGURATION DEMONSTRATED USING UNSTRUCTURED-GRID METHODOLOGY

Russ D. Rausch
Purdue University

John T. Batina
Unsteady Aerodynamics Branch

RTOP 505-63-50

Research Objective: The objective of the research is to develop a time-marching aeroelastic analysis method that uses Euler equation aerodynamics for wing/body configurations.

Approach: A novel aspect of the method is that the analysis was performed using unstructured grids made up of tetrahedra that allow the analysis of complex three-dimensional configurations. The structural dynamic equations of motion were incorporated into a three-dimensional, unstructured-grid, upwind Euler code. To perform an aeroelastic analysis, a steady solution was calculated and used to determine the static aeroelastic deformations. The structure then was given an initial excitation, and the structural equations and unsteady Euler equations were integrated in time simultaneously for a given value of dynamic pressure q. The aeroelastic transients were analyzed to determine if the amplitude of the motion increased (unstable) or decreased (stable) with time. When seeking a flutter point in subsequent analyses, the dynamic pressure either was increased, if the motion was stable, or was decreased, if the motion was unstable.

Accomplishment Description: A flutter analysis was performed for a supersonic transport (SST) configuration with a fuselage, clipped delta wing, and two identical rearward mounted nacelles. The upper left part of the figure shows the SST model mounted in the Transonic Dynamics Tunnel, and a partial view of the surface mesh is shown at the bottom of the figure. An aeroelastic time-marching calculation was performed for a freestream Mach number M_∞ of 0.907 and zero degrees mean angle of attack α_0. The responses were analyzed for their damping and frequency components to determine the flutter characteristics, which were found to be in good agreement with those measured during wind-tunnel tests. The aeroelastic responses of the first three structural modes are shown at the right of the figure for a dynamic pressure equal to the experimental flutter dynamic pressure q_{exp}. The computed responses are nearly neutrally stable, indicating good agreement with the measured aeroelastic behavior.

Significance: The results are the first wing/body flutter calculations obtained using the unstructured-grid Euler equation methodology for three-dimensional configurations.

Future Plans: Plans are to develop a highly accurate and efficient solution algorithm for the Euler and Navier-Stokes equations for aeroelastic analysis of complex aircraft configurations.

Figure 25 (a).

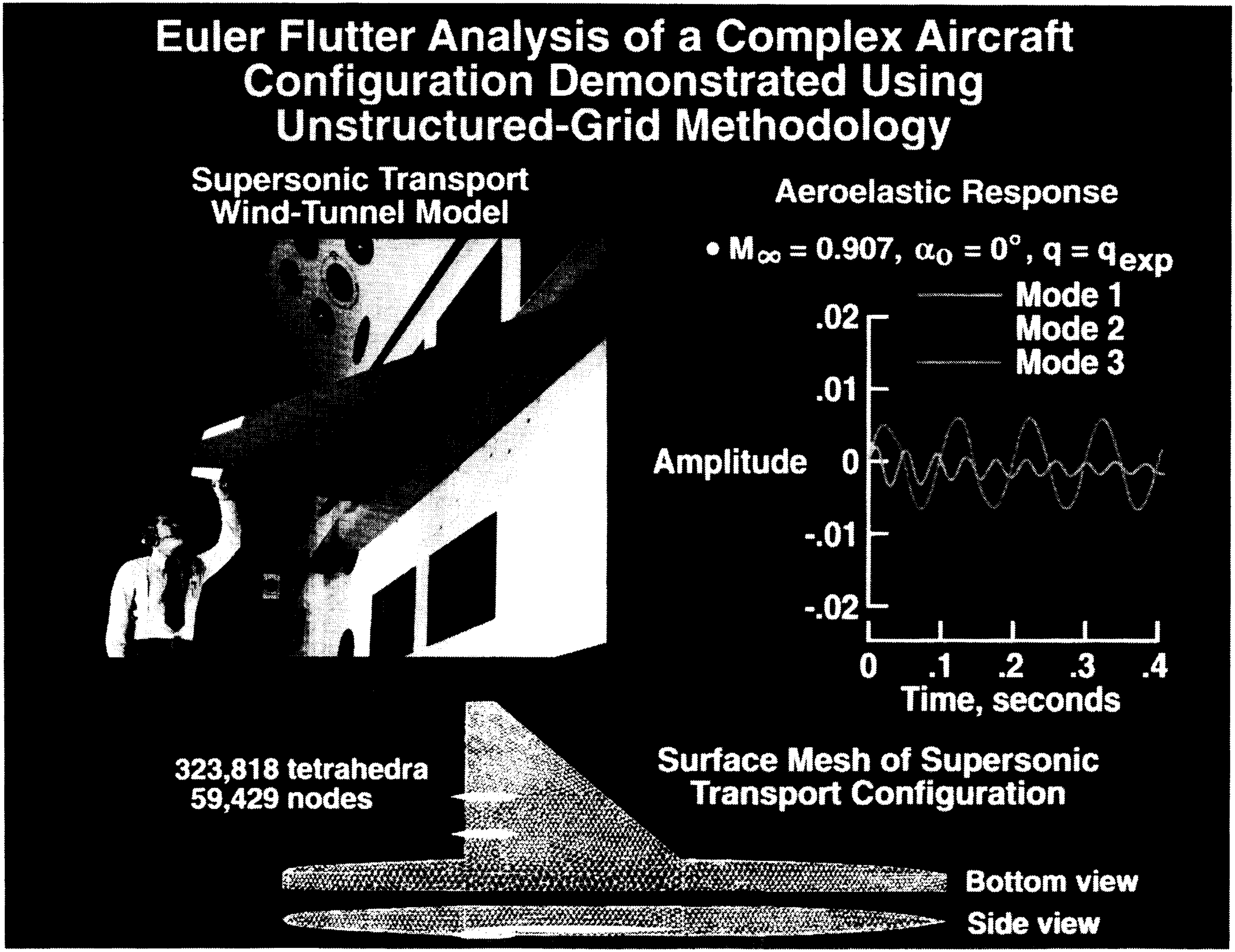

Euler Flutter Analysis of a Complex Aircraft Configuration Demonstrated Using Unstructured-Grid Methodology
Supersonic Transport Wind-Tunnel Model
Aeroelastic Response
• $M_\infty = 0.907$, $\alpha_0 = 0°$, $q = q_{exp}$
Mode 1
Mode 2
Mode 3
Amplitude
.02
.01
0
-.01
-.02
0
.1
.2
.3
.4
Time, seconds
323,818 tetrahedra
59,429 nodes
Surface Mesh of Supersonic Transport Configuration
Bottom view
Side view

Figure 25 (b).

SIMULATION OF TAIL BUFFET USING DELTA WING/VERTICAL TAIL CONFIGURATION

Osama A. Kandil, Hamdy A. Kandil, and Ahmed A. Salman
Old Dominion University

RTOP 505-63-50

Research Objective: The main objectives of the present research work are to numerically simulate the tail buffet problem and investigate its control for a delta wing/vertical tail configuration. The effects of configuration aerodynamic parameters and tail aeroelastic parameters on the tail-buffet response are extensively studied.

Approach: Three sets of equations are used to solve the fluid dynamics and aeroelastic parts of the problem. The unsteady, compressible full Navier-Stokes equations are used for the flow field vector and the surface-pressure distribution. An implicit, upwind, flux-difference splitting, finite-volume scheme is used to obtain the solution. The aeroelastic equations for bending and torsion modes are solved for the deflection responses. The Galerkin method and a four-stage Runge Kutta scheme are used to obtain the solution. The unsteady Navier-displacement equations are solved using the alternating direction implicit scheme for the grid displacements. Time-accurate stepping is used to advance the solutions because of the unsteady nature of the problem.

Accomplishment Description: The attached figure shows a snapshot of the total-pressure contours and particle traces for a delta-wing/rectangular-vertical-tail configuration at the initial condition. The flow Mach number is 0.5, the Reynolds number is 10,000 and the delta-wing angle of attack is 35°. The wing aspect ratio AR_w is 1, and the tail aspect ratio AR_t is 1.5. The tail is placed at 0.5 root-chord of the wing downstream of the wing trailing edge. The grid consists of 125 x 85 x 84 points in the wrap-around, radial and axial directions, respectively. The total-pressure contours and particle traces show the asymmetric vortex breakdown of the left and right leading-edge primary vortices (looking in the downstream direction). The left vortex breakdown occurs on the wing near the trailing edge and the right vortex breakdown occurs outside the wing beyond the trailing edge. It is clearly observed that the vertical tail is subjected to an asymmetric flow that produces asymmetric surface pressure.

Significance: The results of the present investigation have demonstrated the capability of producing asymmetric vortex breakdown, at this high angle of attack, which in turn produces asymmetric unsteady load. Such a prediction is needed in order to solve the three sets of equations for the tail aeroelastic responses and the grid displacements as well as the asymmetric unsteady loads.

Future Plans: The frequencies of the unsteady pressure at the tail surface are computed using Fourier harmonic analysis. The structural properties such as the density, mass moment of inertia, modulus of elasticity and modulus of rigidity are chosen such that one or more of the tail natural frequencies are near to those of the unsteady surface pressure at the tail. Thus, the three sets of equations are sequentially computed. The effects of aerodynamic and aeroelastic limit on the tail responses are being investigated.

Figure 26 (a).

SIMULATION OF TAIL BUFFET USING DELTA WING/VERTICAL TAIL CONFIGURATION

Total-Pressure Contours and Particle Traces

$M_\infty = 0.5$, $R_e = 10^4$, $\alpha = 35^\circ$, $AR_w = 1.0$, $AR_t = 1.5$, $125\times85\times84$ grid points

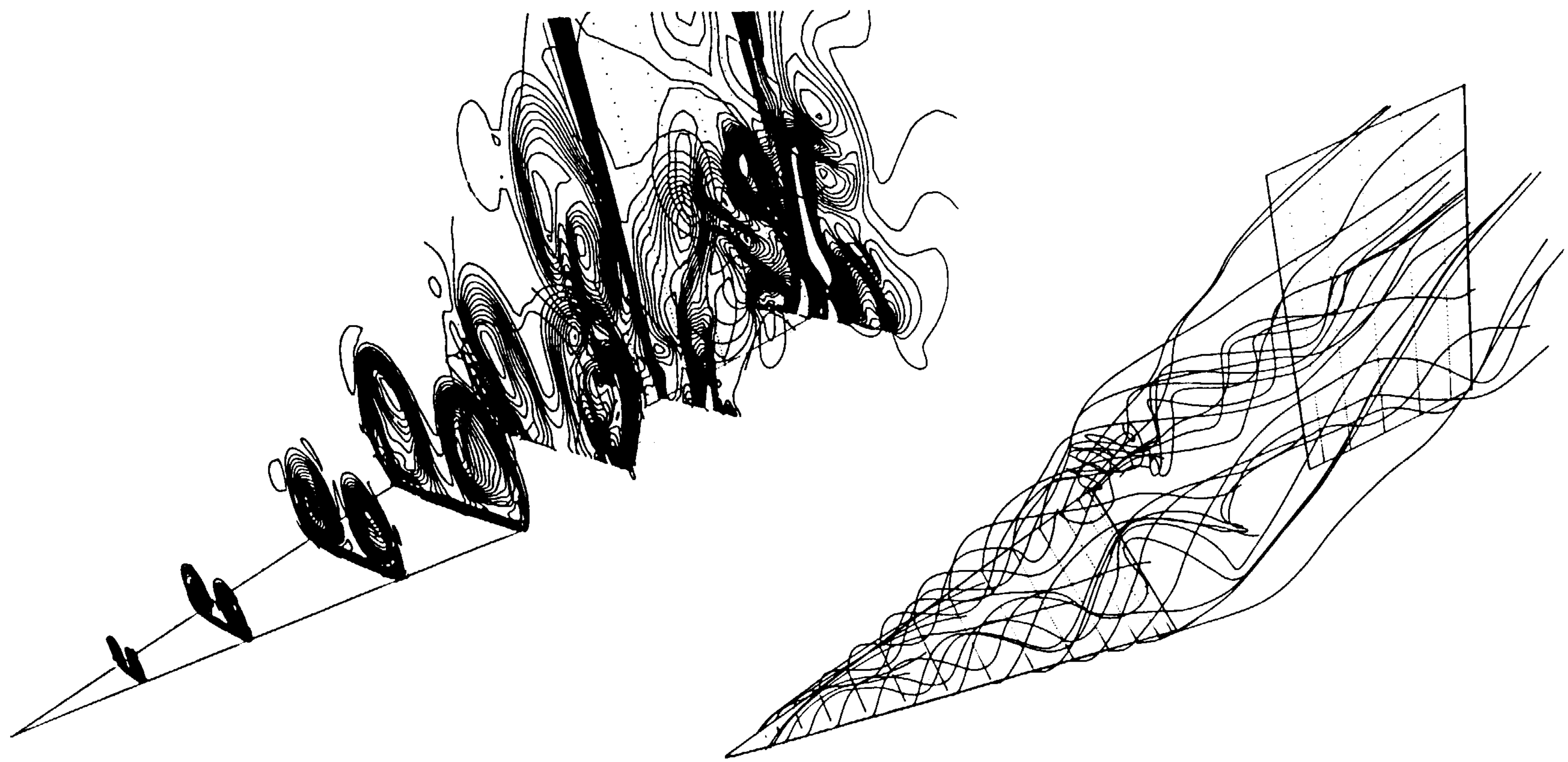


Figure 26 (b).

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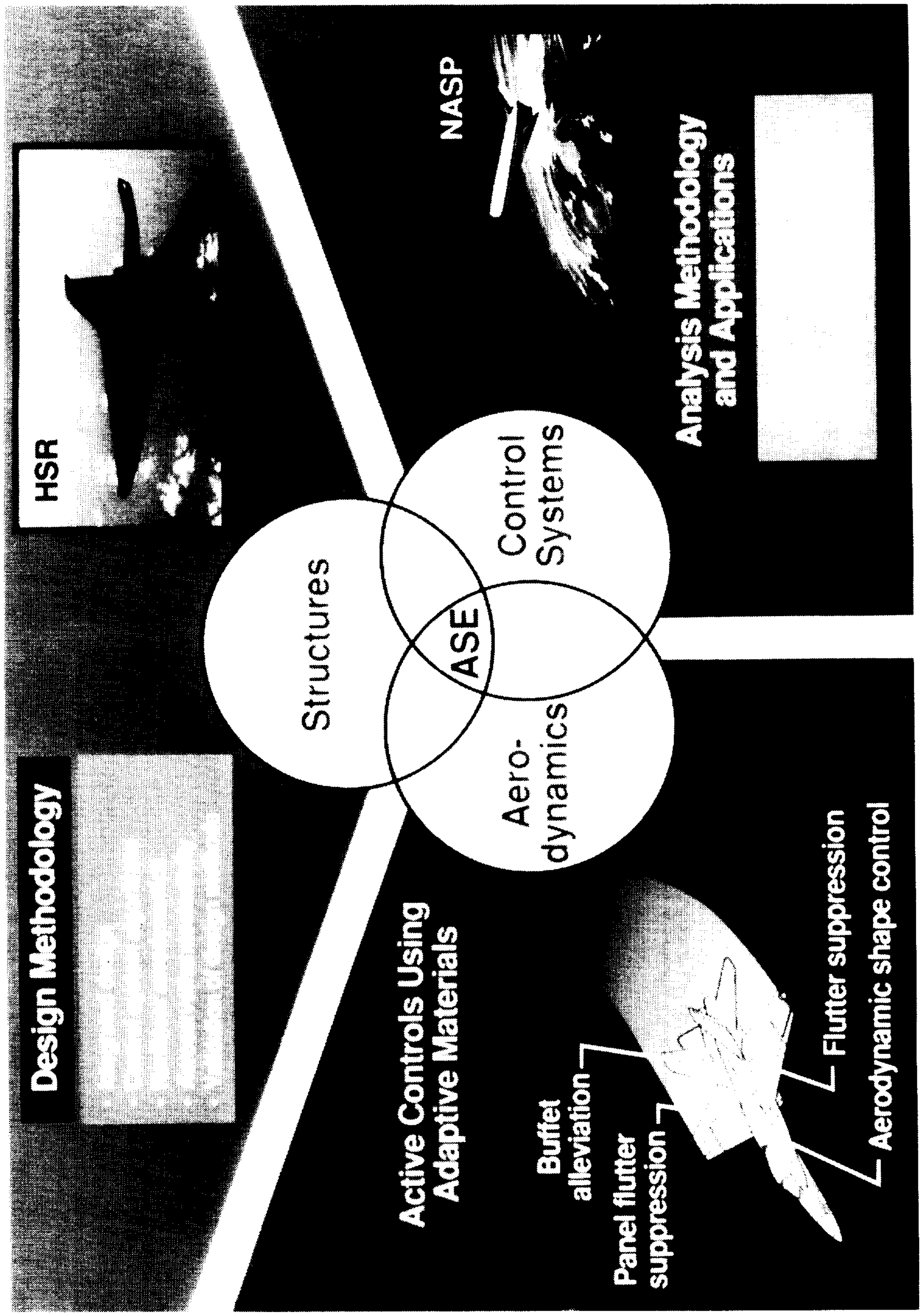

Figure 27.

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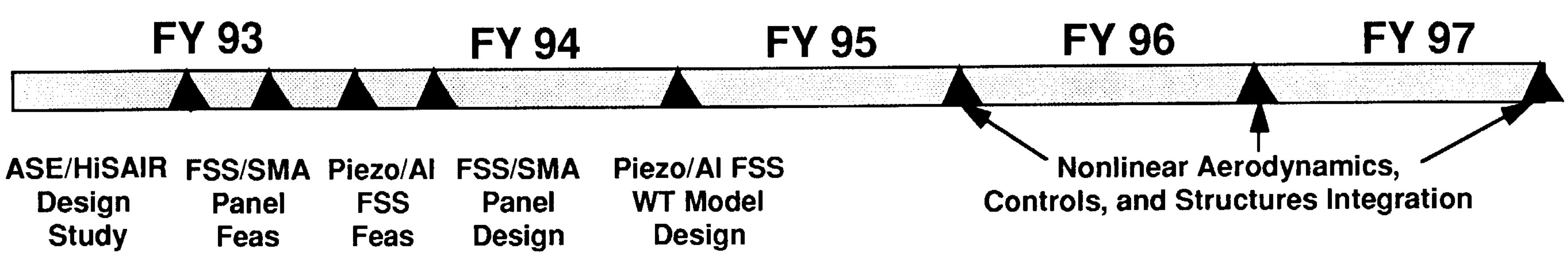
ACTIVE CONTROL OF AEROELASTIC RESPONSE
FUTURE PLANS (FY 93-97)

GOAL

DEVELOP ACTIVE CONTROLS TECHNOLOGY

KEY OBJECTIVES

- MODELING, ANALYSIS, AND DESIGN METHODS



- HARDWARE AND TEST ARTICLES

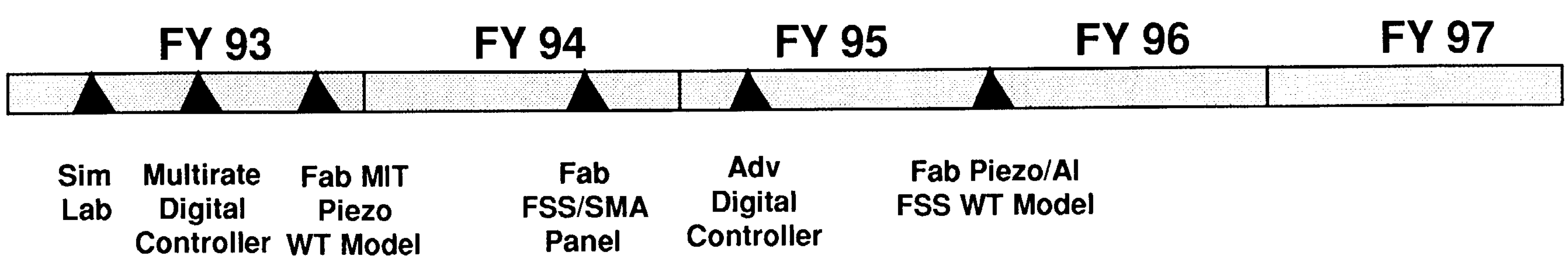


Figure 28 (a).

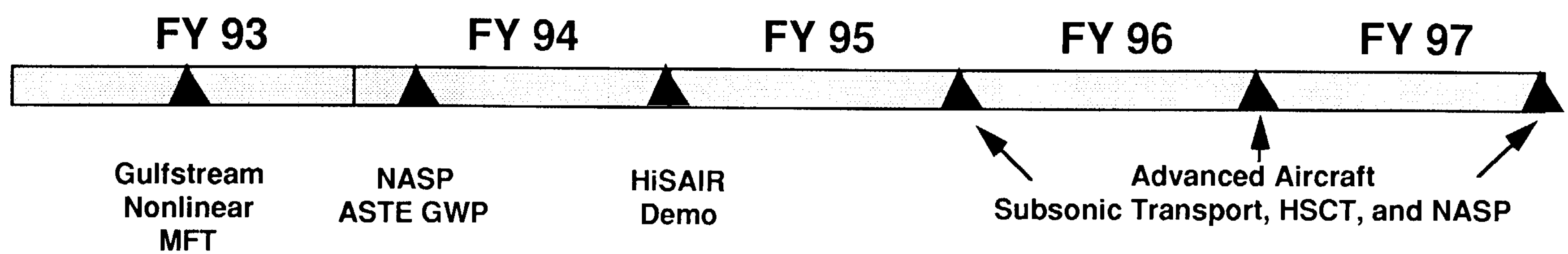
ACTIVE CONTROL OF AEROELASTIC RESPONSE FUTURE PLANS (FY 93-97)

GOAL

APPLY ACTIVE CONTROLS TECHNOLOGY

KEY OBJECTIVES

- APPLICATIONS



- TEST DEMONSTRATIONS

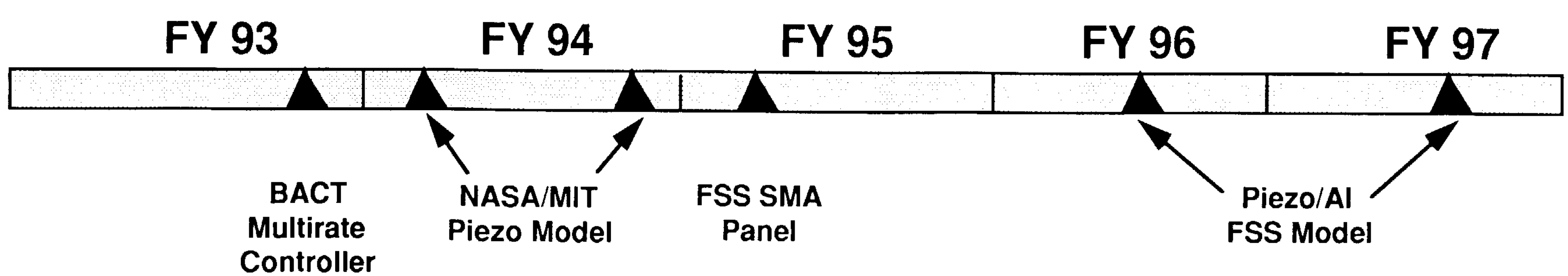


Figure 28 (b).

MULTIRATE FLUTTER SUPPRESSION SYSTEM DEVELOPED FOR THE BACT WIND-TUNNEL MODEL

Martin C. Berg and Gregory S. Mason
University of Washington

Vivek Mukhopadhyay and Carol D. Wieseman
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: The objectives of this investigation are to: 1) develop a methodology for designing and analyzing robust multirate digital control laws; and 2) demonstrate the benefits of multirate control by applying this methodology to the design of a multirate flutter suppression system for the Benchmark Active Controls Testing (BACT) wing.

Approach: The multirate design methodology was developed in three segments: 1) modeling of the multirate system; 2) synthesizing of the multirate compensator; and 3) analyzing the performance and robustness of the multirate system. Multirate system modeling and compensator synthesis was based on the Generalized Multirate Control Law Structure and on a low-order multirate synthesis algorithm, both of which were previously developed at the University of Washington. Together they were used to model and synthesize low-order multirate compensators with independent sample/update rates for each compensator input, output, or digital processor state. To improve the robustness of the multirate control laws, the synthesis algorithm was modified so that it could account for multiple plant conditions.

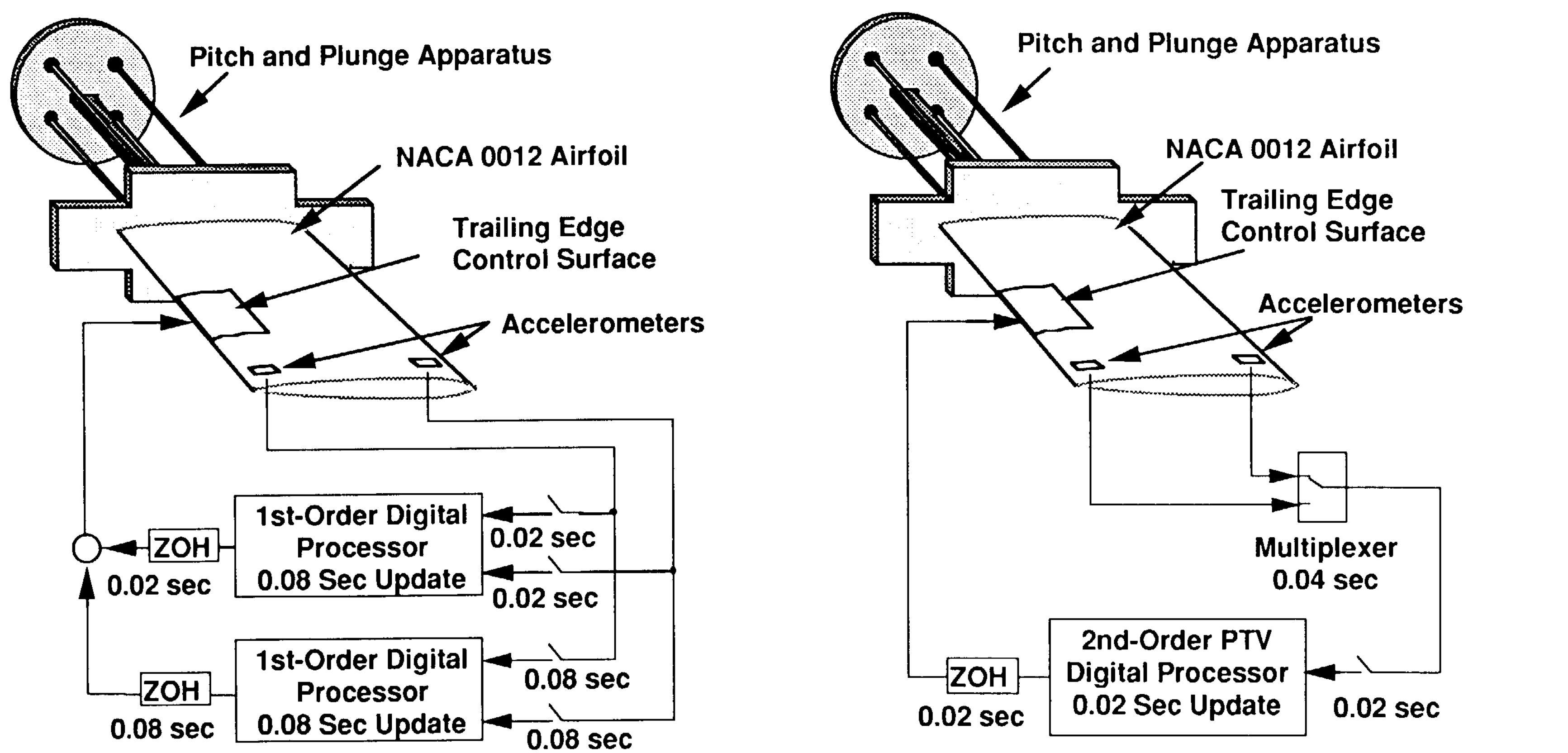
Accomplishment Description: Two multirate flutter suppression systems were designed for the BACT wing to match the performance and robustness of a single-rate compensator. Each flutter suppression system was designed to stabilize the wing at 24 different flight conditions, with Mach numbers ranging from 0.50 to 0.78 and dynamic pressures from 75 pounds per square feet (psf) to 225 psf in a heavy gas medium. One design uses two multirate compensators as shown in the left figure. The other design (shown in the right figure) samples the accelerometers at 25 Hz in a multiplexed fashion, but feeds back the responses at a rate of 50 Hz to a compensator with periodically time varying (PTV) gains. The value of the PTV gains depends upon accelerometer signal being read.

Significance: The advantage of using a multirate compensator approach is that it requires either fewer real-time multiplications or half as many analog-to-digital (A/D) conversions to implement than conventional single-rate systems.

Future Plans: The two multirate control law concepts will be refined to improve their robustness particularly due to uncertainty in the A/D converters. These control laws will be tested in the Transonic Dynamics Tunnel using the BACT model to validate the design methodology.

Figure 29 (a).

MULTIRATE FLUTTER SUPPRESSION SYSTEM DEVELOPED FOR THE BACT WIND-TUNNEL MODEL



Multirate Compensator with Successive Loop Closure Structure

Multirate Compensator with Multiplexed Input and Periodically Time-Varying Digital Processor Gains

Figure 29 (b).

STOCHASTIC-SIMULATION-BASED METHOD FOR PREDICTING TIME-CORRELATED GUST LOADS VALIDATED

Robert C. Scott and Boyd Perry III
Aeroservoelasticity Branch

Anthony S. Pototzky
Lockheed Engineering and Sciences Co.

RTOP 505-63-50

Research Objective: The objective of this activity was to validate a new method for computing maximized and time-correlated gust loads. This validation involved investigating a suspected relationship between an established method and the new method. The established method, the Matched-Filter Method (MFM), was formulated and validated in 1988; the new method is a Stochastic-Simulation-Based Method (SSM).

Approach: The approach involved applying both methods to the same math model and comparing answers. To simplify the validation tasks, a linear math model of a transport aircraft equipped with a yaw-damper control system was employed.

Accomplishment Description: The accompanying figure illustrates, on the left, the basic elements of each analysis method and, on the right, comparisons of responses from each method. The upper left box, outlined in red, illustrates the analysis procedure employed in the linear MFM. Here a gust profile (GP) time history is generated by the MF Gust Generator and applied to the linear aircraft model represented by the sketch of the aircraft, resulting in a maximized load (ML) time history and a correlated load (CL) time history. The lower left box, outlined in blue, illustrates the analysis procedure employed in the SSM. Here a gust profile is generated by the SS Gust Generator and applied to the same model, resulting in two load time histories. Still within the SSM, an extraction and averaging procedure is then employed. This procedure involves searching the time history of one of the loads for peak values that satisfy certain criteria, extracting segments of all three time histories in the vicinity of these peaks, and averaging the like time histories. The time histories are then multiplied by the generally-accepted factor relating peak values in a random process to the standard deviation of the process. The three plots on the right side of the figure contain comparisons of the averaged extracted results, just described, and the results from the linear MFM. The time histories obtained from the SSM are very similar to those obtained from the MFM, confirming a relationship between the two methods and validating the SSM.

Significance: Within the past several years there has been much interest in obtaining a practical analysis method that is capable of solving for design gust loads for highly nonlinear aircraft. The SSM, when applied to a highly nonlinear aircraft, could be significantly "cheaper, better, and faster" than existing methods for such aircraft.

Future Plans: The SSM will be applied to a highly nonlinear aircraft, and answers will be compared with those from existing methods. Linear and nonlinear results will be presented at the 1993 Gust Specialists' Meeting and, if a paper is accepted, at the 1993 AIAA Structures, Structural Dynamics, and Materials Conference.

Figure 30 (a).

STOCHASTIC-SIMULATION-BASED METHOD FOR PREDICTING TIME-CORRELATED GUST LOADS VALIDATED

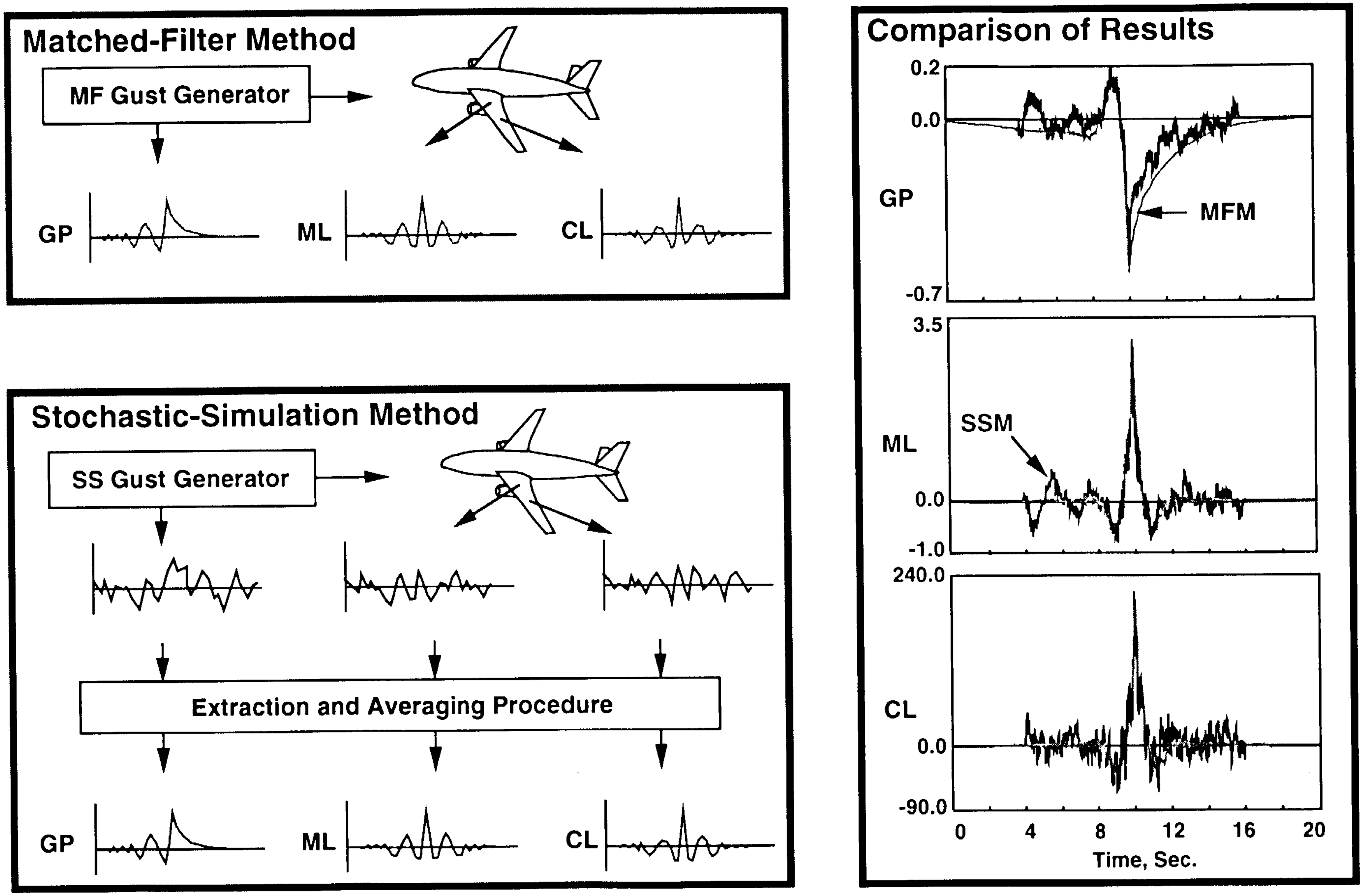


Figure 30 (b).

HYPERSONIC AEROELASTIC ANALYSIS METHOD DEVELOPED USING STEADY CFD AERODYNAMICS

Robert C. Scott
Aeroservoelasticity Branch

Anthony S. Pototzky
Lockheed Engineering and Sciences Corporation

RTOP 505-63-50

Research Objective: The objective of this activity is to develop a small perturbation technique for generating quasi-steady aerodynamic loads on a flexible vehicle from steady CFD calculations. The aerodynamic results obtained by this technique can be used to perform conventional linear flutter analyses and used to generate linear aeroservoelastic models to design and analyze control systems for hypersonic aircraft.

Approach: The technique assumes that the vehicle velocity is very high such that the reduced frequency of important flexible vehicle motions is within the quasi-steady range of aerodynamics. Under these conditions, time constants of the unsteady flow are so small that the aerodynamics acting on the vehicle can be assumed to have no memory. The real part of the pressures are obtained from CFD calculations where the grid has been deformed into the structural mode shapes by a small amount to affect only linear changes. The imaginary parts of the pressure modes are obtained by simulating the small motions of the mode shapes through the a transpiration boundary condition on the surfaces of the vehicle. By the superposition assumption, the generalized aerodynamic forces computed from the pressure modes can be used to perform linear flutter analysis and aeroservoelastic modeling.

Accomplishment Description: To develop confidence in the technique, steady and unsteady CFD calculations were performed on a National AeroSpace Plane-like all-moveable wing using the CFL3D code. The imaginary parts of the surface pressure contours shown in the top left of the figure were computed using a steady CFL3D calculation with the transpiration boundary condition to describe the motion of the wing pitch mode. These pressures compare favorably with the pressures shown at the bottom left of the figure which were obtained using an unsteady CFL3D calculation of the wing under a sinusoidal pitch motion. Flutter analyses, using eight flexible wing modes, were performed using the quasi-steady aerodynamic procedure described above and, separately, using unsteady aerodynamics predicted by piston theory. The resulting normalized flutter dynamic pressure predictions are shown on top right of the figure for Mach numbers 5, 10 and 15. The quasi-steady results show close agreement with piston theory at the low Mach number range, but at the higher Mach numbers the two curves deviate substantially indicating piston theory to be highly conservative as expected.

Significance: At hypersonic speeds, the aerodynamics predicted by applying the quasi-steady technique would provide more accurate and potentially less conservative flutter results than using unsteady aerodynamics from the more commonly available piston and Newton impact theories. The quasi-steady technique goes beyond piston and Newton impact theories by including the steady nonlinear aerodynamics effects of the perturbation point. These more accurate quasi-steady aerodynamics will result in a more realistic flutter sizing of hypersonic vehicles and, possibly, lighter structural weights. In addition, the technique is much cheaper and faster than using fully unsteady CFD aerodynamics for aeroelastic calculations.

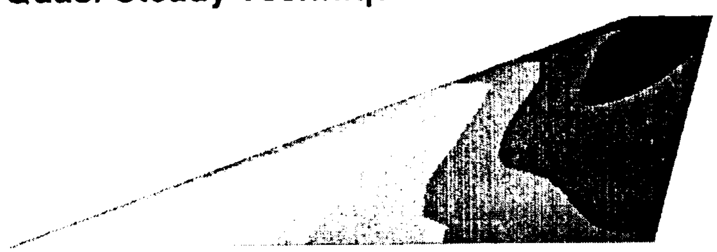
Future Plans: A paper describing the quasi-steady aerodynamic procedure and its application to a NASP-like wing will be prepared and if accepted, presented at the AIAA Structures, Structural Dynamics, and Materials Conference in 1993.

Figure 31 (a).

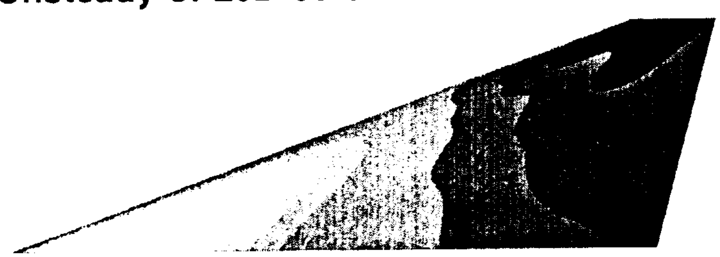
HYPERSONIC AEROELASTIC ANALYSIS METHOD DEVELOPED USING STEADY CFD AERODYNAMICS

Comparison of Imaginary Parts of Differential Pressures

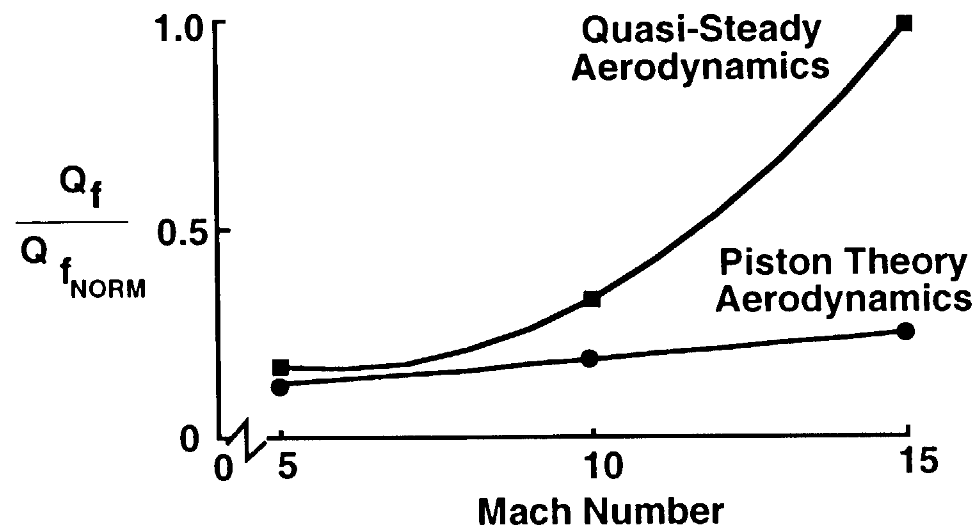
Quasi-Steady Technique



Unsteady CFL3D Calculation



Flutter Results



Payoffs

- Requires Only Steady CFD Calculations
- Models Nonlinear Steady CFD Effects
- Cheaper/Faster than Unsteady CFD Methods
- More Accurate than Unsteady Linear Methods

Figure 31 (b).

IMPLICIT SHEAR DEFORMATION MODEL ENHANCES AEROELASTIC ANALYSIS CAPABILITY

Mark W. Nixon
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: The objective of this research is to improve the predictive capabilities of anisotropic beam-based analyses. Accurate solutions for response, loads, stability, and internal stresses are desired.

Approach: The limitations of beam models are investigated through comparison with both experiment and higher-order analyses such as those based on solid-element finite elements. Specific phenomenon under study, such as shear deformation, are isolated so that the effectiveness of the beam modeling for this trait may be ascertained. Modifications to the beam model are made as necessary to achieve desired accuracy. Expansion of the model complexity is constrained by the implications that this complexity may have on rotorcraft comprehensive analyses of which the beam model is a part.

Accomplishment Description: An anisotropic beam with an implicit shear model has been successfully implemented in a rotorcraft comprehensive analysis known as UMARC (University of Maryland Advanced Rotor Code). Shear deformation has a large effect on blade bending stiffnesses when certain elastic couplings are present, particularly extension-twist coupling. By including additional shear-related degrees of freedom in a beam model, the effect of the shear deformation may be captured as shown on the bar chart on the left. However, the use of additional degrees of freedom unnecessarily complicates and slows the associated comprehensive analysis. An implicit shear deformation model was developed in which the shear-related degrees of freedom are statically condensed from the analysis. The results show that the response is identical to that obtained with the explicit model. Further, the implicit model may also capture the nonclassical shear-related warping effects. A simplified method for including this warping is the application of a shear correction factor which is shown to further improve the predictive capability of the beam model. One concern in the application of an extension-twist-coupling concept is the adverse effect that it has on blade bending modes since the bending stiffness is reduced by the coupling. However, the rotor blade also has bending stiffness due to centrifugal effects which can dominate the total flap and lag response as is illustrated in the tip response plot on the right. This plot shows that large twist deformations may be obtained as desired without large changes in flap deformations.

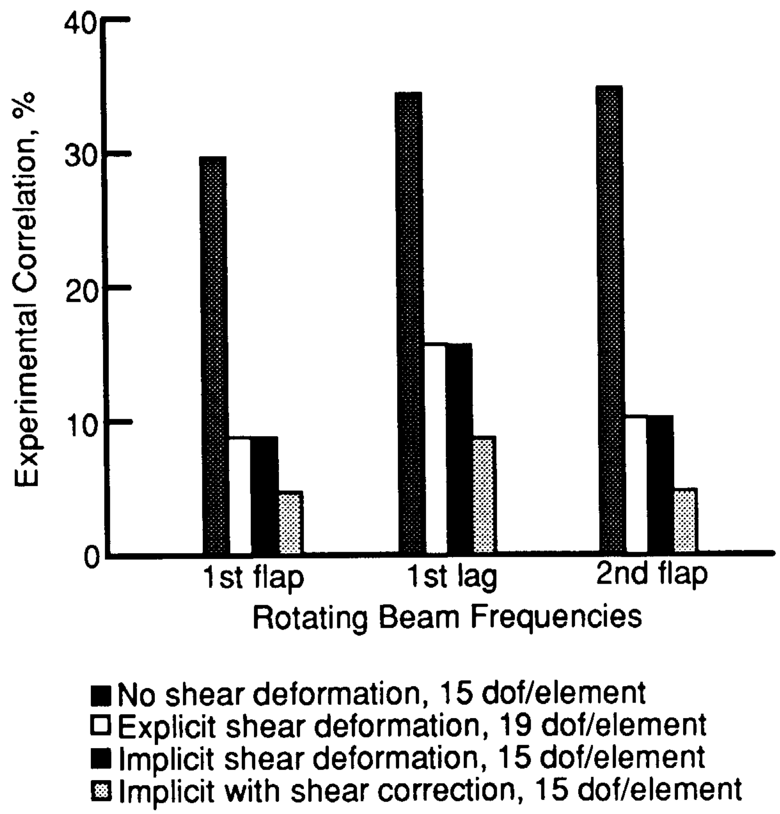
Significance: This research extends the capabilities of some rotorcraft comprehensive analyses to include anisotropic rotor blade models. The results of this work allows concepts for elastic tailoring in rotor blades to be evaluated more thoroughly than in the past.

Future Plans: The comprehensive analysis described above is being extended to include tiltrotor configurations.

Figure 32 (a).

IMPLICIT SHEAR DEFORMATION MODEL ENHANCES AEROELASTIC ANALYSIS CAPABILITIES

Case Study for Shear Deformation Models



Typical Rotor Blade Tip Response

Advance Ratio = .35

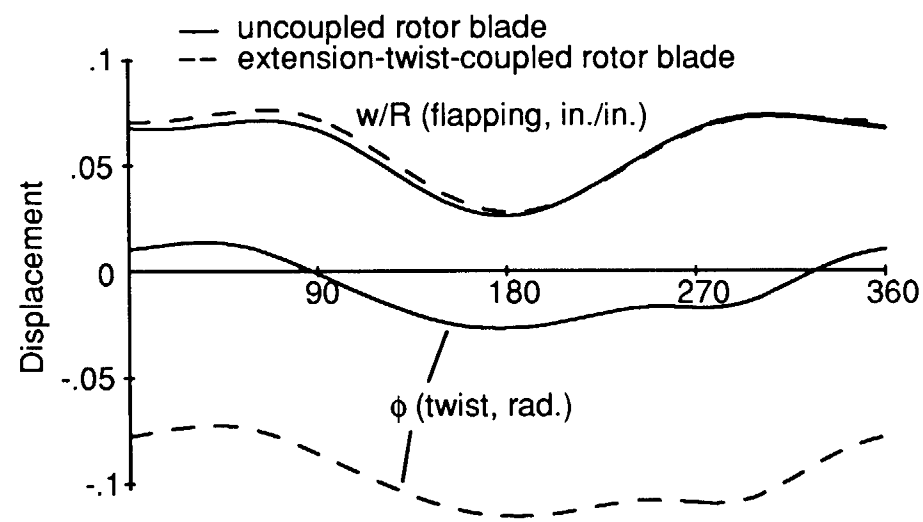


Figure 32 (b).

FLUTTER SUPPRESSION CONTROL LAWS DESIGNED FOR THE BACT WIND-TUNNEL MODEL USING CLASSICAL, LQG, AND H_∞ METHODS

Vivek Mukhopadhyay
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: The objective of this effort was to design robust flutter suppression control laws using state-of-the-art procedures for the Benchmark Active Controls Testing (BACT) wind-tunnel model shown in the sketch in the top right of the figure.

Approach: Designs for the active flutter suppression system control laws were obtained using classical, modified Linear Quadratic Gaussian (LQG), and H_∞ methods. All three of the control law designs used the difference between the wing leading-edge and trailing-edge accelerometers as the feedback signal and the trailing-edge control surface as the force producer. For the classical design, Nyquist and root-locus diagrams were used to establish the feedback gains for pitch rate and pitch angle feedback. For the LQG and H_∞ designs, balanced truncation was used to reduce the order of the state equations.

Accomplishment Description: Control laws were designed to increase the flutter dynamic pressure of 123 psf in air to over 225 psf. Although not shown, Nyquist diagrams indicated that the LQG and H_∞ designs provided better gain and phase stability margins than the classically designed control law. The RMS responses for the three control law designs are compared in the bottom figures. The figures show that the LQG control law has the lowest RMS control activity. Both the LQG and the H_∞ FSS designs are also shown to reduce the gust loads (lift and pitching moment) by 30% and 20% percent respectively, at the open-loop flutter condition (123 psf).

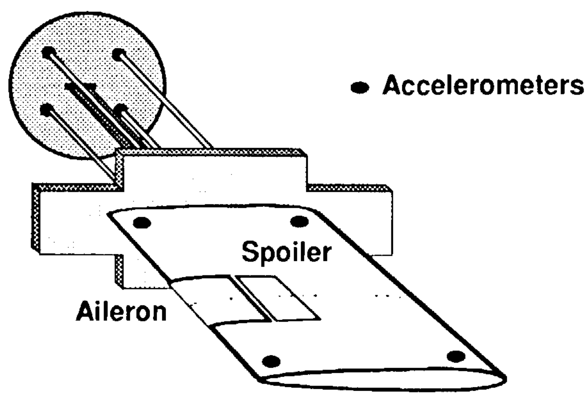
Significance: Besides investigating advanced control law algorithms, actuator nonlinearities (0.3 degrees deadband and 14 degrees saturation) were studied in time simulations. In addition, the use of the upper and lower spoiler surfaces for flutter suppression was studied. The spoiler surfaces were assumed to generate half the aerodynamic force and respond to commands in only one direction. The spoiler simulation studies indicated that the closed-loop system was stable at 200 psf.

Future Plans: A NASA Technical Memorandum summarizing the design study is being prepared for publication. During the 1st series of wind-tunnel tests, open-loop data will be measured to estimate the plant transfer functions, to verify and improve the plant design model, and to enhance the preliminary designs of the candidate control laws. In addition, Controller Performance Evaluation techniques will be used to obtain experimental data to compare the stability margins and performance predictions of the three control laws below flutter. During the 2nd series of wind-tunnel tests (closed-loop above the flutter boundary), measured data will be used to verify and validate the FSS control law design procedures.

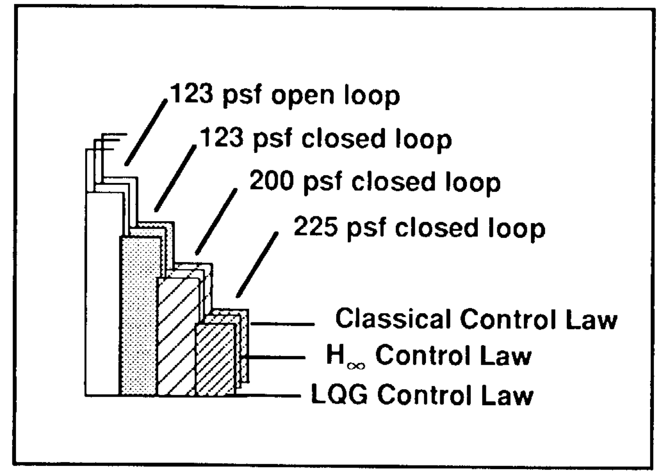
Figure 33 (a).

FLUTTER SUPPRESSION CONTROL LAWS DESIGNED FOR THE BACT WIND-TUNNEL MODEL USING CLASSICAL, LQG AND H_∞ METHODS

BACT WIND-TUNNEL MODEL



LEGEND



ANALYSIS RESULTS

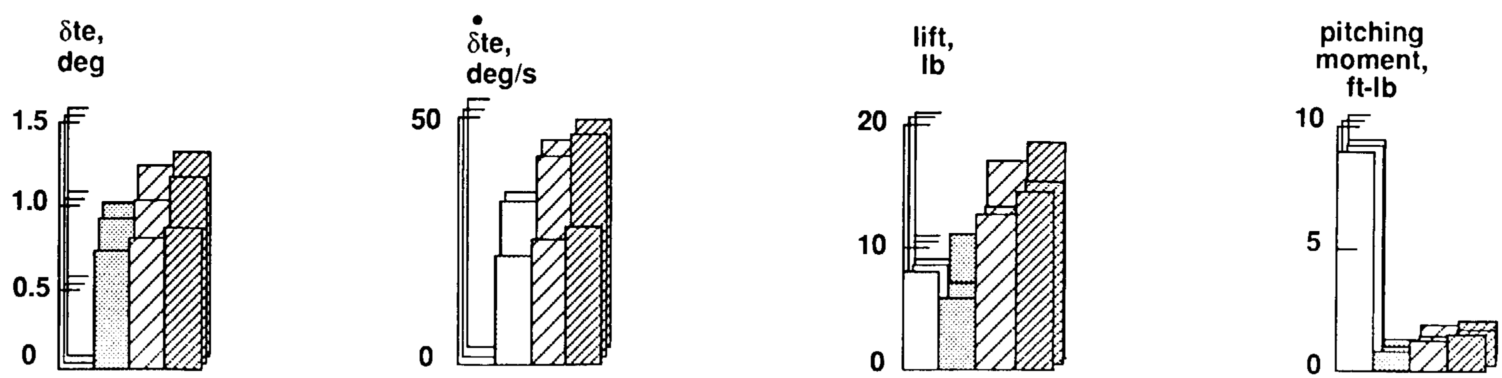


Figure 33 (b).

DIGITAL CONTROLLER SYSTEMS DEVELOPED FOR BACT PROGRAM

Sherwood T. Hoadley
Aeroservoelasticity Branch

Sandy M. McGraw
Lockheed Engineering and Sciences Co.

RTOP 505-63-50

Research Objective: The objectives for the Benchmark Models Program are to provide test data for evaluating new capabilities of computational aeroelasticity codes, increase physical understanding of unsteady flow phenomena, and provide test data for developing empirical design methods where computational methods need further development. Specifically, the objectives for data acquired from wind-tunnel tests of the model for Benchmark Active Controls Testing (BACT) program are to: 1) verify control law analysis methods; 2) verify methodologies for design and analysis of robust multirate digital control laws; and 3) demonstrate the benefits of multirate control.

Approach: The accompanying figure illustrates the approach taken in providing a safe test environment for the BACT wind-tunnel tests. There are two digital controller systems which connect to the model through an Active Switch Box and an Actuator Control Electronics box. The Actuator Control Electronics box houses the analog feedback control electronics which position the control surfaces (a trailing-edge control surface and upper and lower spoilers). The Active Switch Box allows selection of actuator command signals to the model from one of three sources: a manual control, a Passive Digital Controller (PDC), or an Active Digital Controller (ADC). The ADC provides the active digital control of aeroelastic response and performs data acquisition for on-line analysis. The PDC provides a measure of wind-tunnel safety by functioning as a trip system during testing in the case of high model dynamic response or in case the ADC fails.

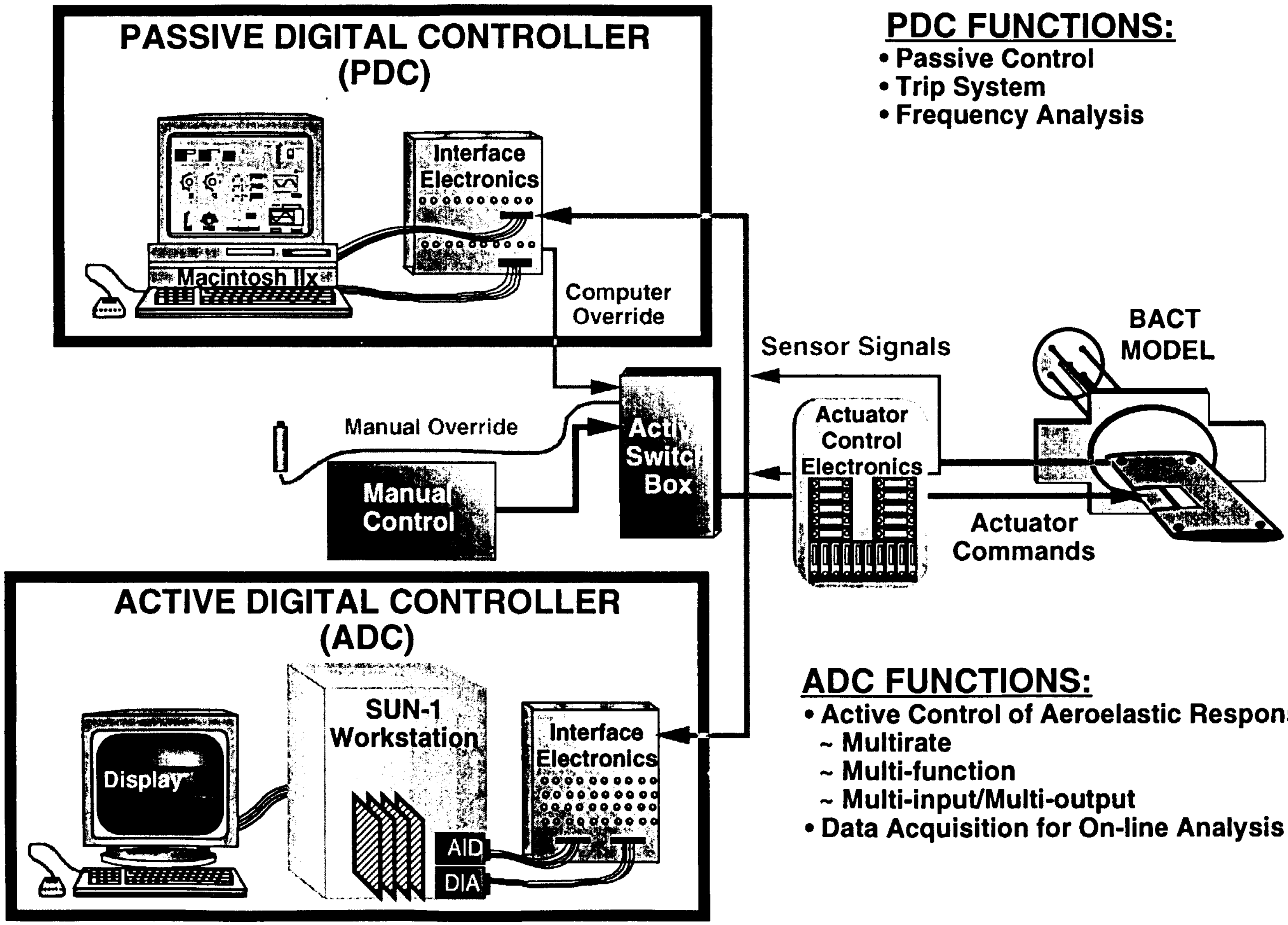
Accomplishment Description: The multi-input/multi-output, multiple-function, ADC, designed originally for the AFW wind-tunnel program, has been modified to include multirate digital control for the BACT program. It also performs data acquisition, storage, and transfer for on-line analysis to evaluate controller performance and to determine the open-loop plant transfer matrix. It is housed in a SUN 3/160 Workstation environment which includes several dedicated digital signal processors and analog/digital conversion boards. The PDC will provide a measure of safety in testing the BACT model in the wind tunnel by monitoring signals and by functioning as a trip system. If specified limits of certain signals such as accelerations, wing deflections, or control surface rates are exceeded, the PDC takes command of the control surfaces from the ADC, commands the control surfaces to predetermined positions, and 'trips' the wind tunnel. Other PDC functions include static deflection of control surfaces, excitation of the control surfaces either singly or in combination, and real-time dual-channel frequency analysis. The Active Switch Box controls which actuator command signals are sent to the model. Switching can be performed manually by a knob on the front panel. This switch can be actively overridden by a computer or manual override signal, switching the selection of actuator signals to a hardware specified selection.

Significance: The digital controller systems and active switching capability developed for the BACT program provide a safe testbed for acquiring data for verifying control law analysis methods and testing multirate digital control laws. The accomplishments described are cost-effective, using hardware which was previously acquired and modifying software which was previously developed for other programs. New codes required minimal development time and new hardware was designed and built in-house.

Future Plans: Two BACT wind-tunnel tests using these controller systems are presently scheduled.

Figure 34 (a).

DIGITAL CONTROLLER SYSTEMS DEVELOPED FOR BACT PROGRAM



PDC FUNCTIONS:
- Passive Control
- Trip System
- Frequency Analysis

ADC FUNCTIONS:
- Active Control of Aeroelastic Response
  - ~ Multirate
  - ~ Multi-function
  - ~ Multi-input/Multi-output
- Data Acquisition for On-line Analysis

Figure 34 (b).

AEROELASTIC CHARACTERISTICS OF NASP DEMONSTRATOR MODEL IDENTIFIED

Jennifer Heeg
Aeroservoelasticity Branch

Thomas A. Zeiler and Anthony S. Pototzky
Lockheed Engineering and Sciences Corporation

RTOP 505-63-50

Research Objective: It's proposed that the National AeroSpace Plane (NASP) will travel at speeds up to Mach 25. Because aerodynamic heating during high-speed flight through the atmosphere could destiffen a structure, significant couplings between the elastic and rigid body modes could result in lower flutter speeds and more pronounced aeroelastic response characteristics. These speeds will also generate thermal loads on the structure. The purpose of this research was to analyze a representative vehicle referred to herein as "the NASP Demonstrator Model" over the range of flight Mach numbers and to determine the vehicle's aerothermoelastic characteristics when subjected to the aerodynamically induced thermal loads.

Approach: A sketch of the NASP Demonstrator configuration is shown in the accompanying figure. In performing this study, symmetric aeroelastic equations of motion for the unheated vehicle and for the heated vehicle as it moves along the flight trajectory shown in the figure were developed and analyzed. In developing the heated vehicle equations of motion, steady aerodynamic calculations at various flight conditions were performed to produce radiation equilibrium wall temperatures. These temperature distributions were then incorporated into the finite element model resulting in changes to the material properties and stiffness characteristics and, subsequently, to the structural mode shapes and frequencies. Matched point flutter analyses of the vehicle were performed using conventional state-of-the-art subsonic, supersonic, and hypersonic linear unsteady aerodynamic theories.

Accomplishment Description: The figure presents some of the results of the matched point symmetric flutter analyses for the unheated and heated vehicle. Within the Mach range from 0 to 25, three types of instabilities were predicted. The 1st instability was an unstable short period mode which occurred throughout the flight envelope for both the unheated and heated vehicle. The 2nd instability was a body freedom flutter mode predicted to occur at high subsonic and low supersonic speeds, but outside the flight envelope (results not shown in the figure). This instability involved a coalescence of the vehicle short period and the wing pivot modes. The 3rd instability was a flutter mode that involved coalescence of the wing pivot mode with the 1st fuselage bending mode. This instability was predicted to be the closest to the flight trajectory and, therefore, the results are shown in the figure for both the unheated and heated vehicle. The results indicate that the heated vehicle is more susceptible to aeroelastic instabilities as a result of the destiffening structure due to aerodynamic heating.

Significance: This investigation has concluded that flight vehicles similar to NASP (highly flexible fuselages, low structural weight to total weight ratio, and severe flight environment) are susceptible to a variety of aeroelastic instabilities. Active controls can play an important role in controlling these instabilities, but the control design task will be difficult.

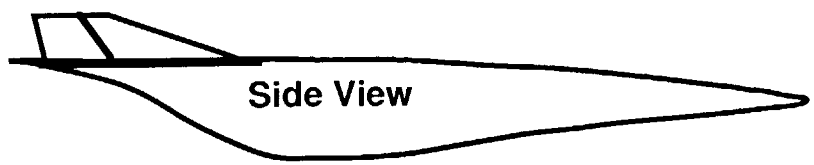
Future Plans: Three papers are being prepared that describe the various activities related to this project. If accepted these papers will be presented at the AIAA Structures, Structural Dynamics and Materials Conference during the spring of 1993.

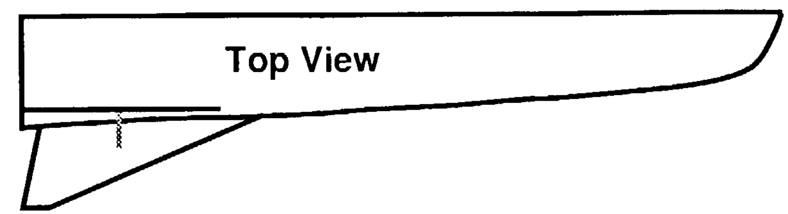
Figure 35 (a).

C-2

AEROELASTIC CHARACTERISTICS OF NASP DEMONSTRATOR MODEL IDENTIFIED

NASP DEMONSTRATOR MODEL





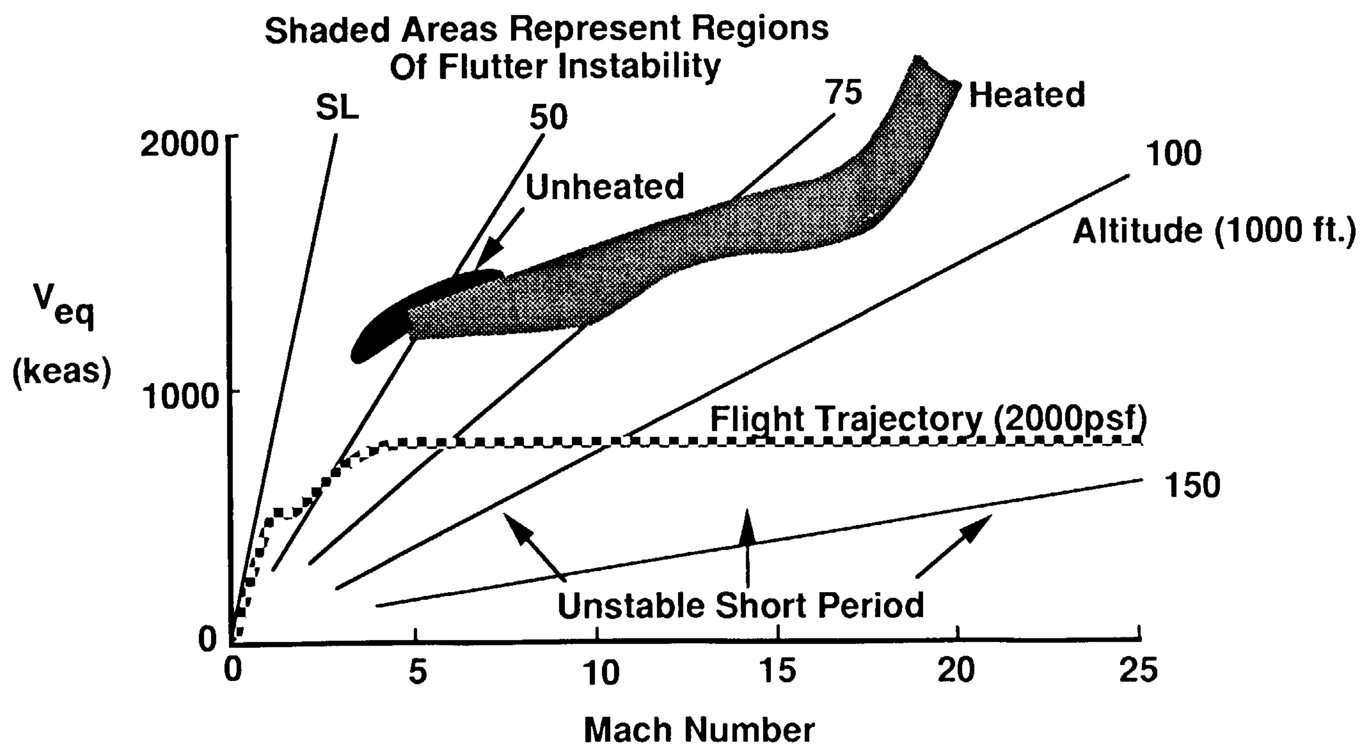


Figure 35 (b).

RESULTS OF AEROELASTIC ANALYSIS OF MACH 2.4 HISAIR CONFIGURATION

Thomas A. Zeiler
Lockheed Engineering and Sciences Company

Jessica A. Woods-Vedeler and Carol D. Wieseman
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: The objective of this continuing research has been to develop and implement methods to integrate aeroservoelastic analysis into the HiSAIR integrated aircraft design effort.

Approach: Aeroelastic Vehicle Analysis (AVA) codes are used to evaluate aeroelastic characteristics of the current Mach 2.4 configuration. Structural information about the configuration was obtained from an equivalent plate model developed in the Interdisciplinary Research Office. Flight envelope information was obtained from the Vehicle Integration Branch. Based on specific requests from other disciplines, stability and control derivatives, aeroelastic constraints, and design parameters sensitivities were computed and provided to other disciplines for their design and analysis activities.

Accomplishment Description: A contribution to the HiSAIR design effort has been made by performing an aeroelastic analysis of the recent Mach 2.4 configuration. The upper figure summarizes the points of instability determined through analysis of several load cases at different flight conditions. The data shows that several points of static longitudinal instability and flutter occur within the flight envelope. This indicates that in order for the aircraft to fly in these regions, an active flutter suppression system and/or stability augmentation system or structural redesign would be required. Stability and control derivatives were computed and provided to control system designers. These derivatives were C_{L_α}, $C_{L_{\dot\alpha}}$, C_{L_q}, C_{M_α}, $C_{M_{\dot\alpha}}$, C_{M_q}, C_{L_δ}, and C_{M_δ}. The ratio of flexible to rigid C_{L_δ} is shown in the lower figure as a function of equivalent airspeed for each of the two inboard and two outboard control surfaces. Data is from analysis of the configuration at Mach 1.2. It is seen that as equivalent airspeed increases, the aircraft control surfaces experience a decrease in control effectiveness and, finally, control reversal. Such information is critical to the design of an active control system. Finally, AVA has also continued to be developed. AVA is a set of computer codes being developed for the HiSAIR application and provides a fast, efficient means of evaluating the aeroelastic characteristics of an aircraft configuration such as described above. In the past year, AVA has been used for other applications within the Aeroservoelasticity Branch such as the National AeroSpace Plane, piezoelectric flutter suppression, the Benchmark Models Program, and STS orbiter tail loads.

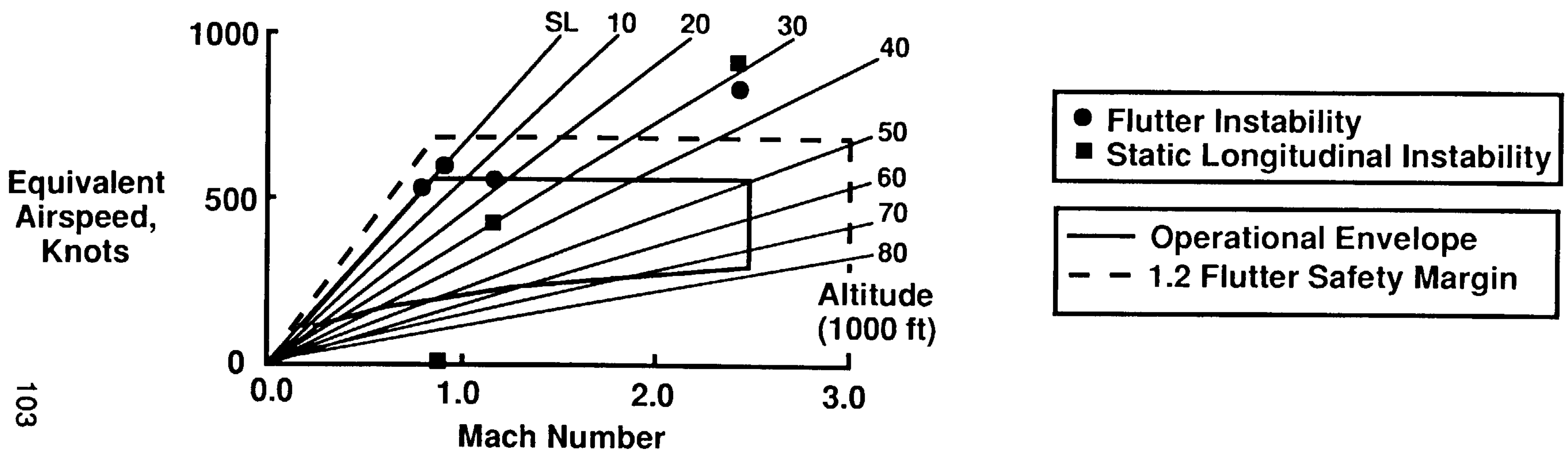
Significance: Methodologies have been and are continuing to be developed which provide a means for aeroservoelastic technology to impact the preliminary design of an aircraft.

Future Plans: AVA will continue to be enhanced to include more advanced capabilities. Methodology will be developed to evaluate the design parameter sensitivities of a closed-loop active controller. Methodology will be developed in conjunction with the structures discipline to allow flutter sizing constraints to be incorporated into structural design model. The methodology for computing aeroelastic design parameter sensitivities such as $\delta V_{eq\ divergence}/\delta y$ and $\delta V_{eq\ flutter}/\delta y$ and aeroelastic constraints has already been coded in AVA and will be evaluated. Analysis of current design configurations will continue.

Figure 36 (a).

RESULTS OF AEROELASTIC ANALYSIS OF MACH 2.4 HISAIR CONFIGURATION

FLIGHT ENVELOPE CLEARANCE



CONTROL SURFACE REVERSAL

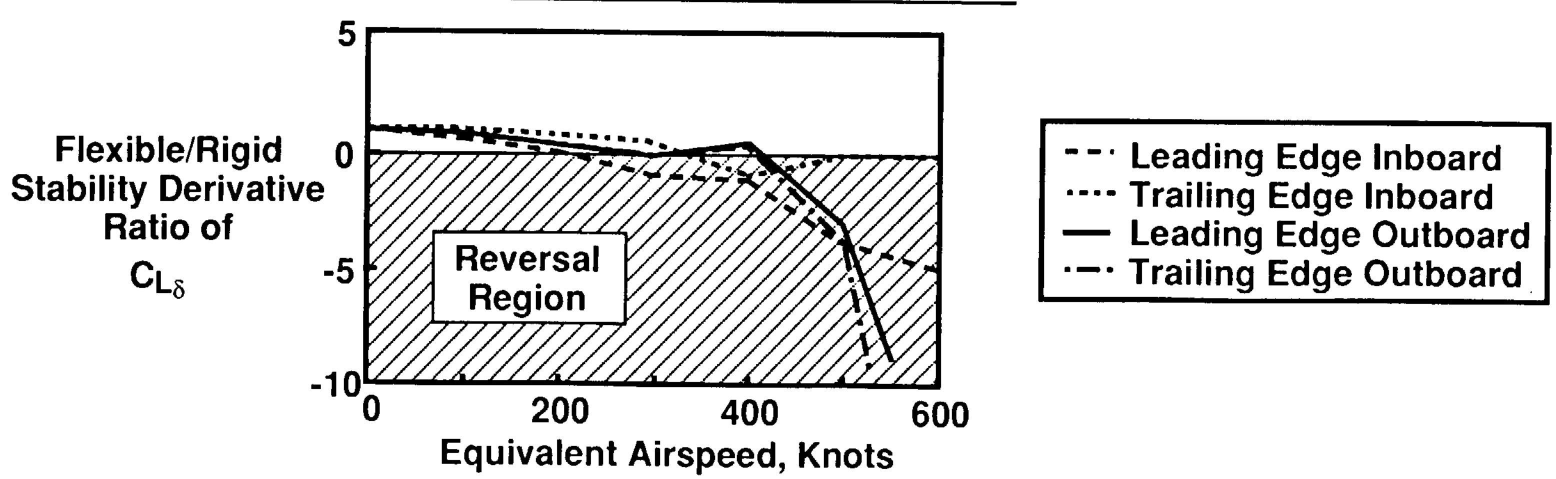


Figure 36 (b).

AEROELASTIC ANALYSIS TOOLS FOR HiSAIR PROJECT VERIFIED ON SIMPLE MULTIDISCIPLINARY DESIGN PROBLEM

Carol D. Wieseman and Jessica A. Woods-Vedeler
Aeroservoelasticity Branch

Thomas A. Zeiler
Lockheed Engineering and Sciences Company

RTOP 505-63-50

Research Objective: The objective was to demonstrate, on a simple optimization problem, aeroelastic analysis tools developed to support the High Speed Airframe Integration Research (HiSAIR) project's multidisciplinary design optimization studies.

Approach: The example problem was to design a flexible pitch and plunge apparatus (PAPA) on which is mounted a rigid wing model. The solution process was set up to parallel the HiSAIR design organization. A top level optimization, shown in the top left of the figure, receives analysis results and sensitivity data from the structures and aeroelasticity disciplines and uses these data in formulating the optimization problem. The structures discipline is represented by simplified analyses of the PAPA structure solving beam and plate equations for the effective plunge mass and constraint functions on buckling, stress, deflections, and frequency separation. Sensitivities of these data with respect to structural design variables are computed also. The structural analyses also supply the aeroelasticity discipline with the structural data needed for calculating flutter and divergence constraints and sensitivities. A design iteration is then performed to minimize the effective plunge mass while satisfying all constraints. The freedom of the design variables to change is restricted by move limits to protect the accuracy of the linearized optimization formulation. At the end of each iteration, a new set of design variables are returned to the structures discipline, and the process repeats until the optimization converges. A NASTRAN model of the evolving PAPA structure is periodically updated with current values of the design variables to verify eigenvalue, mode shape, and generalized mass and stiffness calculations of the simplified analyses. This also parallels the HiSAIR optimization organization wherein a complex finite element model of the subject vehicle is maintained as a "truth-check" of the simplified plate model being used in the optimization for its simplicity and relative computational speed.

Accomplishment Description: Sample optimization results are shown in the figure. The objective function is shown at the upper right. Two aeroelastic constraints, a flutter and a divergence constraint are shown below. The asterisks are linear estimates of the values based on sensitivities from the previous iteration. These demonstrate the accuracy of the aeroelastic sensitivity calculations. The solid line connects points that are calculated by each of the structures and aeroelastic disciplines at each design iteration with the new values of the design variables.

Significance: Computational tools, developed within the Aeroservoelasticity Branch for support of the HiSAIR project, have been demonstrated and their accuracy has been verified. The operational experience of using the tools within the context of a multidisciplinary design problem has been gained, and they can now be applied to a more complex design problem within the HiSAIR project.

Future Plans: A HiSAIR objective is to examine the benefits of incorporating active aeroelastic control in early stages of vehicle design. The Aeroservoelasticity Branch will provide control law designs and closed-loop analyses of the HiSAIR vehicle in addition to the open-loop analyses. Accordingly, techniques for incorporating aeroelastic control law design into the multidisciplinary design problem will be developed, as shown in the upper left of the figure. The closed-loop techniques will also be verified on a simple closed-loop design problem such as described herein.

Figure 37 (a).

AEROELASTIC ANALYSIS TOOLS FOR HiSAIR PROJECT VERIFIED ON SIMPLE MULTIDISCIPLINARY DESIGN PROBLEM

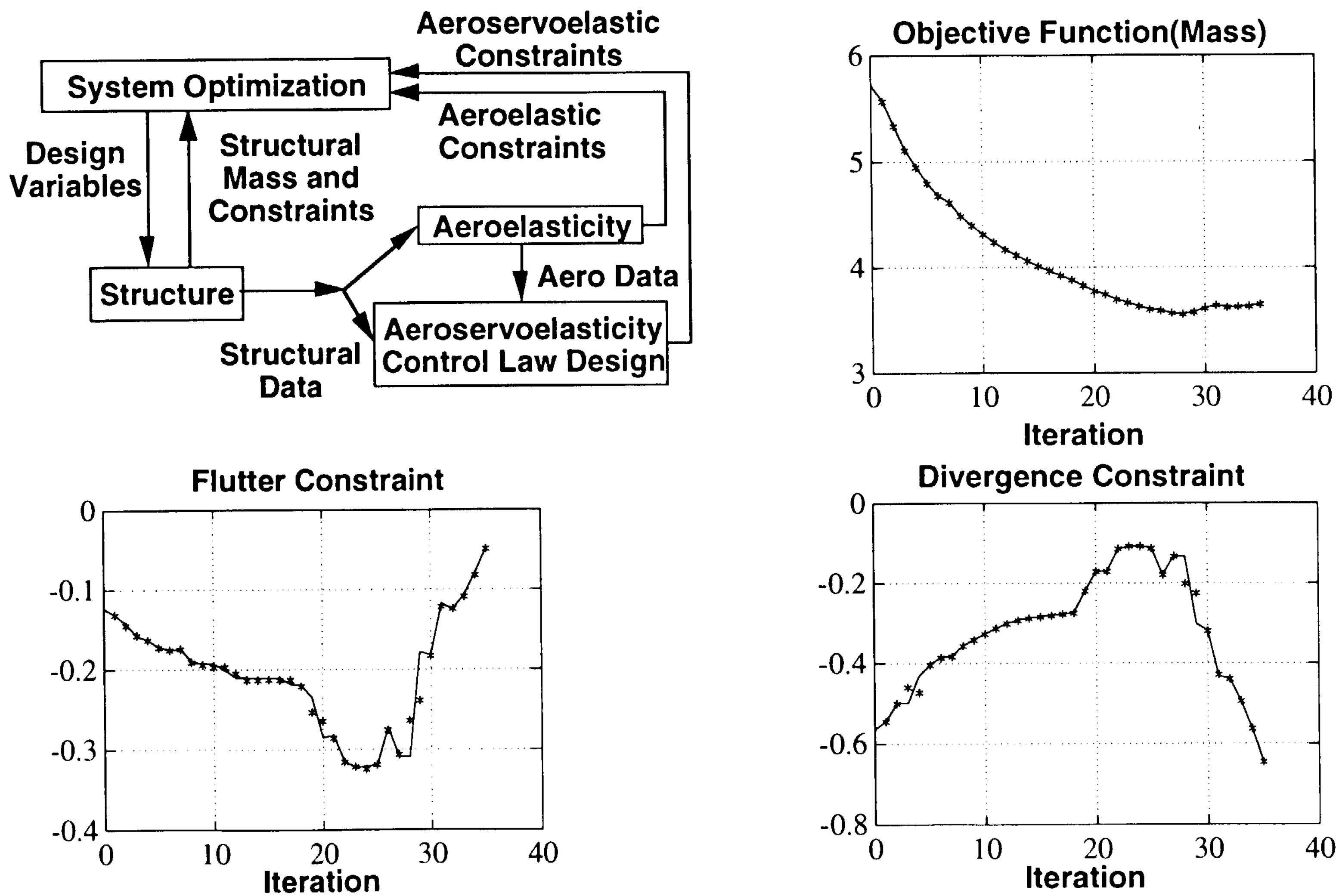


Figure 37 (b).

TECHNIQUE TO EXTRACT "UNALIASED" POWER SPECTRA FROM ALIASED POWER SPECTRA

Robert K. Sleeper and Boyd Perry III
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: One of the objectives of the parent research project of the present work is to obtain simple analytical expressions for the power spectral density functions (power spectra) of the vertical and lateral velocity components of turbulence in the test section of the Langley Transonic Dynamics Tunnel (TDT). Using a constant-temperature anemometer equipped with a hot-film X-probe, time histories of the components of tunnel turbulence were measured in air for a limited number of Mach numbers and at an atmospheric stagnation pressure. The data were sampled at 200 samples per second, yielding a Nyquist frequency (f_N) of 100 Hertz. Due to inadequate antialiasing filtering, the resulting power spectra contained significant amounts of aliasing (as characterized, in the upper-left corner of the figure, by a "curling up" of the measured spectra at frequencies approaching f_N), and thereby putting the project objective in jeopardy. The specific objective of the present work was to develop a technique to extract the "unaliased" power spectra from the aliased power spectra to permit the accomplishment of the project objective.

Approach: An assumed simple expression, consistent with the familiar Dryden and Von Kármán forms of atmospheric-turbulence power spectra, was chosen for the unaliased power spectrum (left center of figure). Based on this simple expression, the corresponding expression for the aliased power spectrum (right center) was derived. These two expressions will be referred to as the unaliased spectral model and the aliased spectral model, respectively. As illustrated in the upper-right sketch, the aliased spectral model is comprised of the sum of all spectral segments "folded" about frequencies zero and f_N. The approach was to employ an unconstrained optimizer to choose the values of quantities α, β, γ, and n (referred to as the optimized quantities) which minimized the sums of the squares of weighted differences between the aliased spectral model and the aliased measured spectrum. Once the optimized quantities are known, the unaliased spectral model would be completely defined at all test conditions and, hence, this part of the project objective would be satisfied. Aliased, unaliased and measured spectra are shown in the plot at upper left.

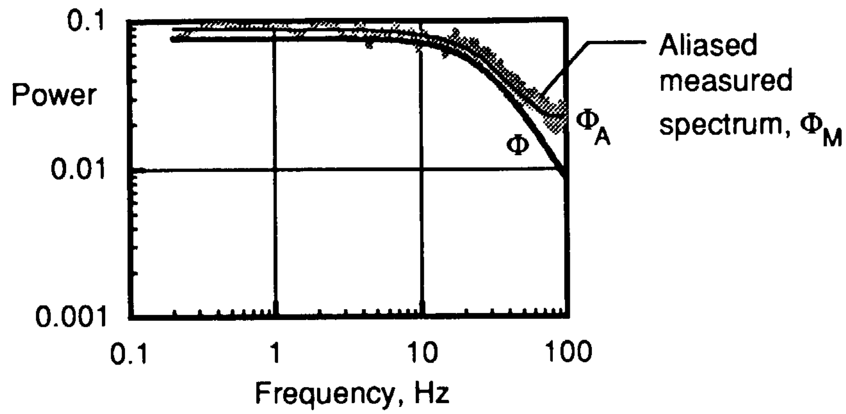
Accomplishment Description: The above approach was first verified using an aliased Dryden spectrum and then implemented successfully for all measured power spectra, resulting in values of the optimized quantities. From these optimized quantities and from other information, additional quantities—the integral scale length (L) and the normalized break frequency (f_b')—were derived . To put these results in perspective, comparisons were made between the quantities from tunnel turbulence and the corresponding quantities from the Dryden and Von Kármán forms of atmospheric turbulence. The plots at the bottom of the figure contain the most significant comparisons. Over the range of tunnel velocities, the values of quantities n and f_b' are in close agreement with the corresponding Dryden and Von Kármán values. For atmospheric turbulence the quantity L has a typical value of 2500 feet and is related to the average eddy size; for tunnel turbulence the value of L was about 4 feet, orders of magnitude below 2500 feet, but, more importantly, smaller than the 16-foot test section size and therefore consistent with the interpretation of average eddy size.

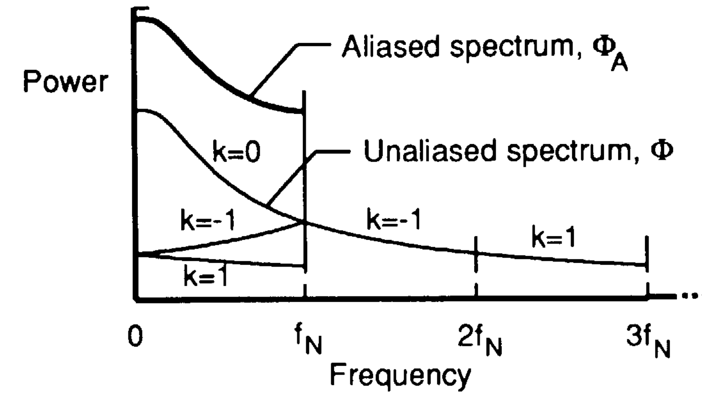
Significance: This technique is applicable to any dynamic system whose power spectral density function may be represented by a relatively simple analytical expression.

Future Plans: A NASA Technical Memorandum will be published soon and a paper will be presented at the ASME Forum on Fluid Measurements and Instrumentation in June 1993.

Figure 38 (a).

TECHNIQUE TO EXTRACT "UNALIASED" POWER SPECTRA FROM ALIASED POWER SPECTRA





Unaliased Spectral Model

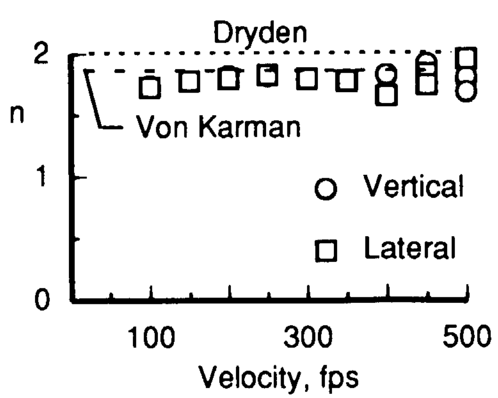
$$\Phi = \alpha \frac{1 + \beta f^2}{(1 + \gamma f^2)^n}$$

Aliased Spectral Model

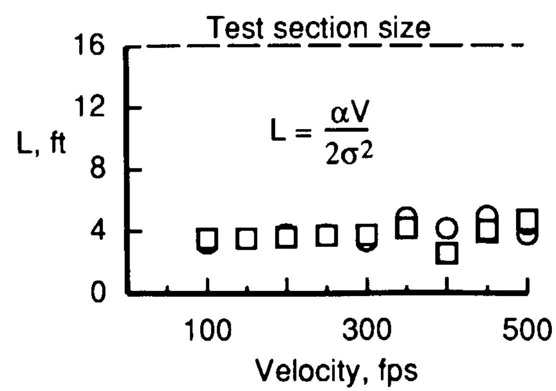
$$\Phi_A = \alpha \sum_k \frac{1 + \beta (f + 2 k f_N)^2}{[1 + \gamma (f + 2 k f_N)^2]^n}$$

where k = 0, ±1, ±2, ...

Exponent, n



Integral Scale Length, L



Normalized Break Frequency, f_b'

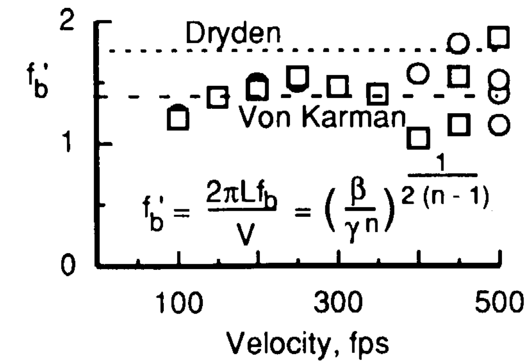


Figure 38 (b).

BUFFET LOAD ALLEVIATION ACCOMPLISHED VIA PIEZOELECTRIC ACTUATION

Jennifer Heeg
Aeroservoelasticity Branch

Robert Doggett
Structural Dynamics Division

Jonathan Miller
Cornell University

RTOP 505-63-5

Research Objective: Fighter aircraft operating at high speeds and at high angles-of-attack quite often experience severe buffeting of the empennage and wing structures. The buffet phenomena generally involves airflow separating from the forward sections of the aircraft at high angles-of-attack resulting in the formation of a vortex flow pattern over the aft sections of the vehicle. If the vortex bursts and the resulting turbulent flow impinges directly on a lifting surface, the buffeting can be quite destructive. Operation of military aircraft at these flight conditions has caused severe structural damage resulting in increased cost of maintenance, reduced operational capability, and lost operational readiness. Common solutions to the buffet problem are to add structure so that the surface can withstand the buffeting airloads or to divert the turbulent flow away from the surface. These passive techniques degrade performance and are very costly. An alternate solution is to apply active controls principles (top figure) using piezoelectric actuators embedded in the structure.

Approach: This experiment was conducted in an open-circuit table-top wind tunnel. A rigid wing was placed upstream of the test section to generate a wake flow representative of a wing-horizontal tail configuration. In the test section, a rigid horizontal tail was attached to a flexible mount system (left figure) which provided a single-degree-of-freedom plunging motion. The control system actuators were made of lead zirconate titanate, a piezoelectric ceramic, and were affixed to flexible leaf springs of the mount system. A strain gage bridge was also mounted on the leaf springs to provide a strain-proportional feedback signal to the digital control computer. A gain feedback control law was implemented on the digital controller and tested. Open- and closed-loop values of a parameter proportional to strain were compared to provide a measure of the system performance.

Accomplishment Description: For the closed-loop buffet experiments, increased damping and decreased response magnitudes in the critical elastic mode was demonstrated. By comparing the root mean square value of the strain parameter with the active system off and on at various test conditions (right figure), the loads are shown to be reduced on the average about 32 percent over the entire velocity range tested; at specific velocity conditions, the strain parameter, and thus the buffet loads were alleviated by more than 50 percent.

Significance: A unique actuation concept which utilizes smart materials and active control principles has been shown to be an effective approach in alleviating buffet loads. The concept offers promise of being a low weight/low cost approach compared to alternate structural or configurational techniques and should only minimally impact aircraft performance.

Future Plans: Aggressive analytical and experimental investigations on applying smart materials for alleviating undesirable aeroelastic response are continuing. Active and passive control concepts are being studied and the most promising approaches will be validated using large scale flexible wind-tunnel models.

Figure 39 (a).

505-63-5

BUFFET LOAD ALLEVIATION ACCOMPLISHED VIA PIEZOELECTRIC ACTUATION

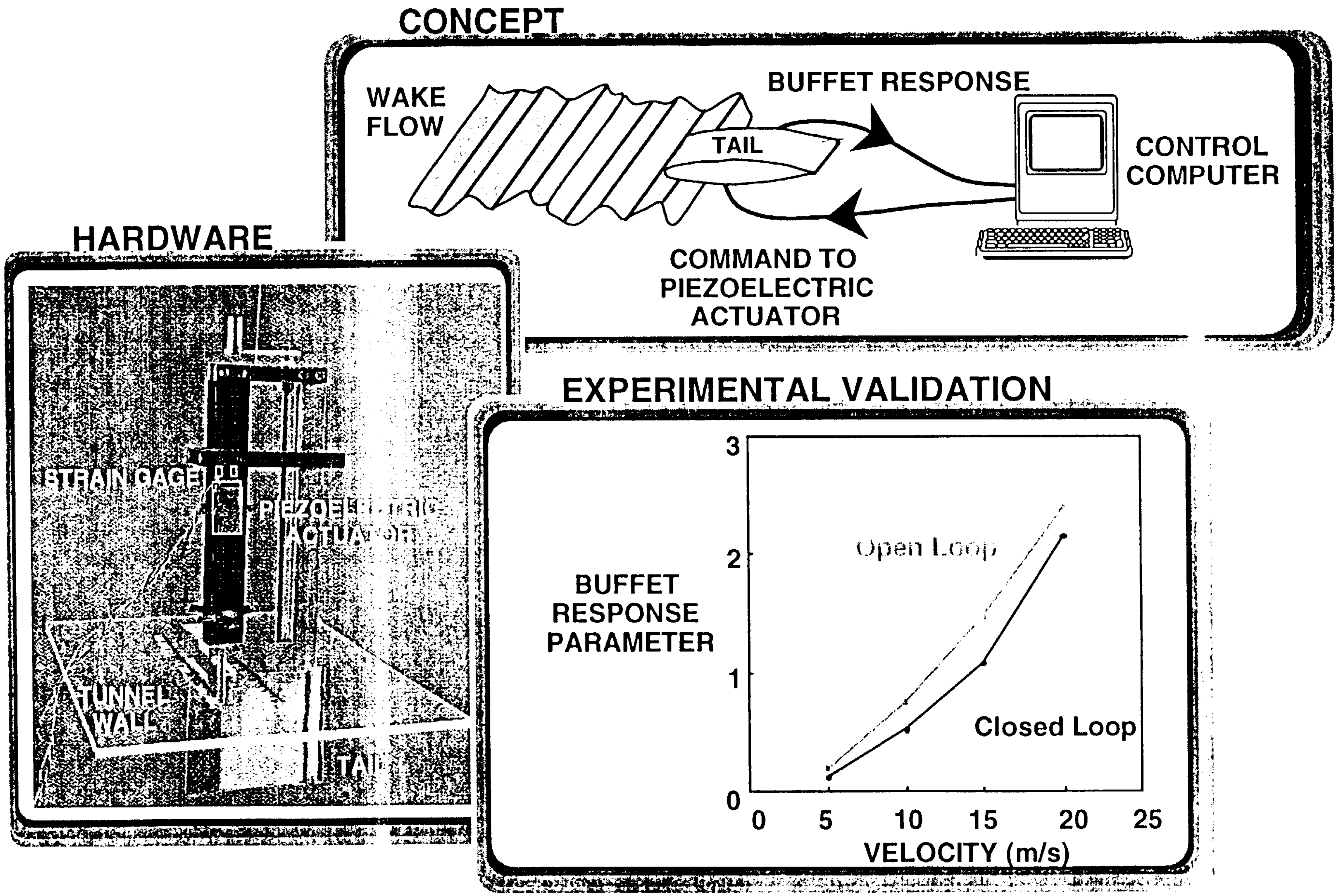


Figure 39 (b).

ACTIVE CONTROL OF PANEL FLUTTER USING PIEZOELECTRIC ACTUATORS STUDIED

Derek A. Paige
Purdue University

Robert C. Scott
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: The objective of this activity is to investigate how piezoelectric materials can be used to control undesirable aeroelastic instabilities in anisotropic composite panels.

Approach: Conventional approaches to controlling panel flutter are shown in the upper left of the figure. The panel stiffness can be enhanced by increasing panel thickness, adding stiffeners, or aeroelastically tailoring the panel to increase its flutter speed. The upper right part of the figure shows the approach taken in this study. Here, piezoelectric actuators are adhered to the upper and lower surfaces of panels and actively controlled to suppress flutter.

Accomplishment Description: Since active control schemes represent increased levels of complexity over conventional passive flutter prevention methods, to be attractive they must offer a significantly lighter weight solution. An analytical panel model that could accommodate anisotropic panel materials, the effects of the induced strain actuators, supersonic aerodynamics, and a turbulence excitation was developed. The piezoelectric material lead zirconate titinate (PZT) was used for the actuators, and the control laws were designed using linear quadratic optimal control. Using this model a variety of parametric studies were conducted including variations of panel geometry, composite lay-ups and ply orientations, and actuator locations. These studies indicated which combinations of actuator locations and panel construction were most suited to the control of panel flutter. In addition, a design study was made demonstrating how a designer may tackle the problem of incorporating piezoelectric materials into panel designs. The lower half of the figure shows the results of this study where an aluminum and a graphite epoxy panel were considered. For each of these panels a nominal panel flutter dynamic pressure was computed and is indicated by the black bars. Then the weight of each of the panels was increased by a set amount. This weight increase resulted from either increasing the panel thickness or adding piezoelectric actuators. The flutter dynamic pressures for these new panels were then computed, and in the case of the piezoelectrically actuated panel, open- and closed-loop boundaries were obtained. The bar charts show that the open-loop performance of the piezoelectrically actuated panels is poor as compared with the equal weight thickened panels, but when the loop is closed the flutter dynamic pressure of the piezoelectrically actuated panels rise above that of the conventionally constructed panel.

Significance: While the use of piezoelectric materials for actively controlling panel flutter has been previously examined for isotropic panels, this is the first study to examine this control scheme for composite panels. By incorporating a turbulence model into the analysis the study has provided a more realistic assessment of this technology than was done in previous studies. In addition, the extensive parametric analysis performed here indicated several unexpected trends that had not been previously uncovered. For instance, it was found for high aspect ratio panels the most efficient use of the actuators requires them to be segmented in both the flow and cross-flow directions.

Future Plans: The results of this study will be presented at the SPIE Smart Structures and Materials Conference to be held during February, 1993.

Figure 40 (a).

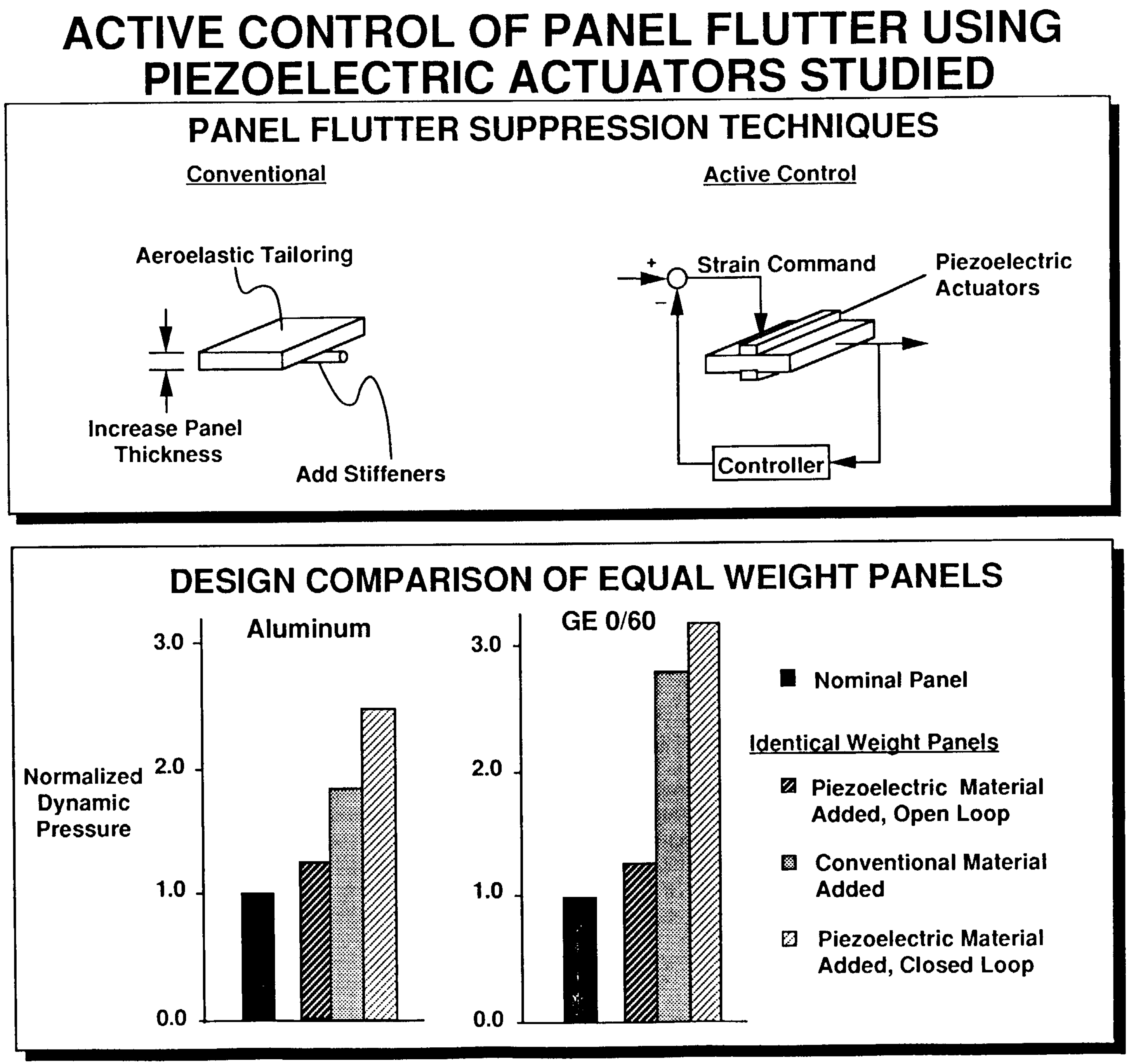

ACTIVE CONTROL OF PANEL FLUTTER USING PIEZOELECTRIC ACTUATORS STUDIED
PANEL FLUTTER SUPPRESSION TECHNIQUES
Conventional
Active Control
Aeroelastic Tailoring
Increase Panel Thickness
Add Stiffeners
+
−
Strain Command
Piezoelectric Actuators
Controller
DESIGN COMPARISON OF EQUAL WEIGHT PANELS
Aluminum
GE 0/60
Normalized Dynamic Pressure
3.0
2.0
1.0
0.0
Nominal Panel
Identical Weight Panels
Piezoelectric Material Added, Open Loop
Conventional Material Added
Piezoelectric Material Added, Closed Loop

Figure 40 (b).

SMALL, SHAPE MEMORY ALLOY ACTUATORS SUPPRESS PANEL FLUTTER

Terrence A. Weisshaar
Purdue University

Robert C. Scott
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: Panel flutter is an unstable aeroelastic phenomenon that occurs in supersonic flows and can be aggravated by thermal stresses due to aerodynamic heating. Very conservative panel flutter prevention criteria and simplified analysis tools presently exist that, when used, quite often results in increased panel thicknesses (and thus weight) to avoid the instability within the flight envelope of the aircraft. At times some panels are not properly represented in the analyses and an instability is unexpectedly encountered during flight testing. Structural changes to prevent the instability at this time can be very expensive. Feasibility studies have been conducted that demonstrated the use of sheets of smart materials as actuators to create inplane stresses in thin panel surfaces in supersonic flow to increase the flutter speed. The objective of this investigation was to extend the previous study by using more accurate models to assess the use of smaller, localized, controlled, shape memory alloy actuators. The use of these micro actuators offer a low weight solution to the panel flutter phenomenon at little cost.

Approach: Studies using a NASTRAN model to complement earlier less sophisticated studies have indicated that large changes in flutter speed can be obtained using small shape memory alloy actuators placed on the underside of panels in supersonic flow. When activated by heat, the actuator contracts and stiffens, causing changes in the panel bending stiffness and inplane stiffness. The addition of a shape memory alloy actuator changes the panel's flutter speed because of slight increases in panel bending stiffness, inertia changes, and significant increases in inplane stresses that tend to separate critical frequencies.

Accomplishment Description: Several different thin panels with different planform geometries, different actuator sizes, and different actuator locations were analyzed. A typical panel model (aspect ratio 2) showing various positions of the actuator is shown in the accompanying figure. The actuator is 1/4 of the thickness of the host panel and covers 1/16 of the plate area. Typical flutter results are presented in the form of a bar chart. Here, the flutter points were determined by holding altitude constant and varying velocity and Mach number to determine the matched flutter point. For comparison purposes the heated panels all had the same temperature of 200° F. The flutter Mach number of a panel without an actuator is decreased when it is heated because of compressive thermal stresses. Three different actuator positions were considered, one at the 1/4 chord position (A), the mid-chord position (B), and the 3/4 chord position (C). The 1/4 position is the most effective. Increases in flutter Mach number are due primarily to advantageous increases in inplane stresses, while decreases in flutter Mach number are due to inertia effects on resonant frequencies.

Significance: The concept of micro-aeroservoelastic actuation has been shown to be an effective method of changing the flutter speed for thin panels. These actuators present a design option for solving localized airframe instabilities.

Future Plans: Studies related to optimal actuator thickness, area, and location are currently being pursued, as is the examination of the limits of effectiveness of this concept.

Figure 41 (a).

SMALL, SHAPE MEMORY ALLOY ACTUATORS SUPPRESS PANEL FLUTTER

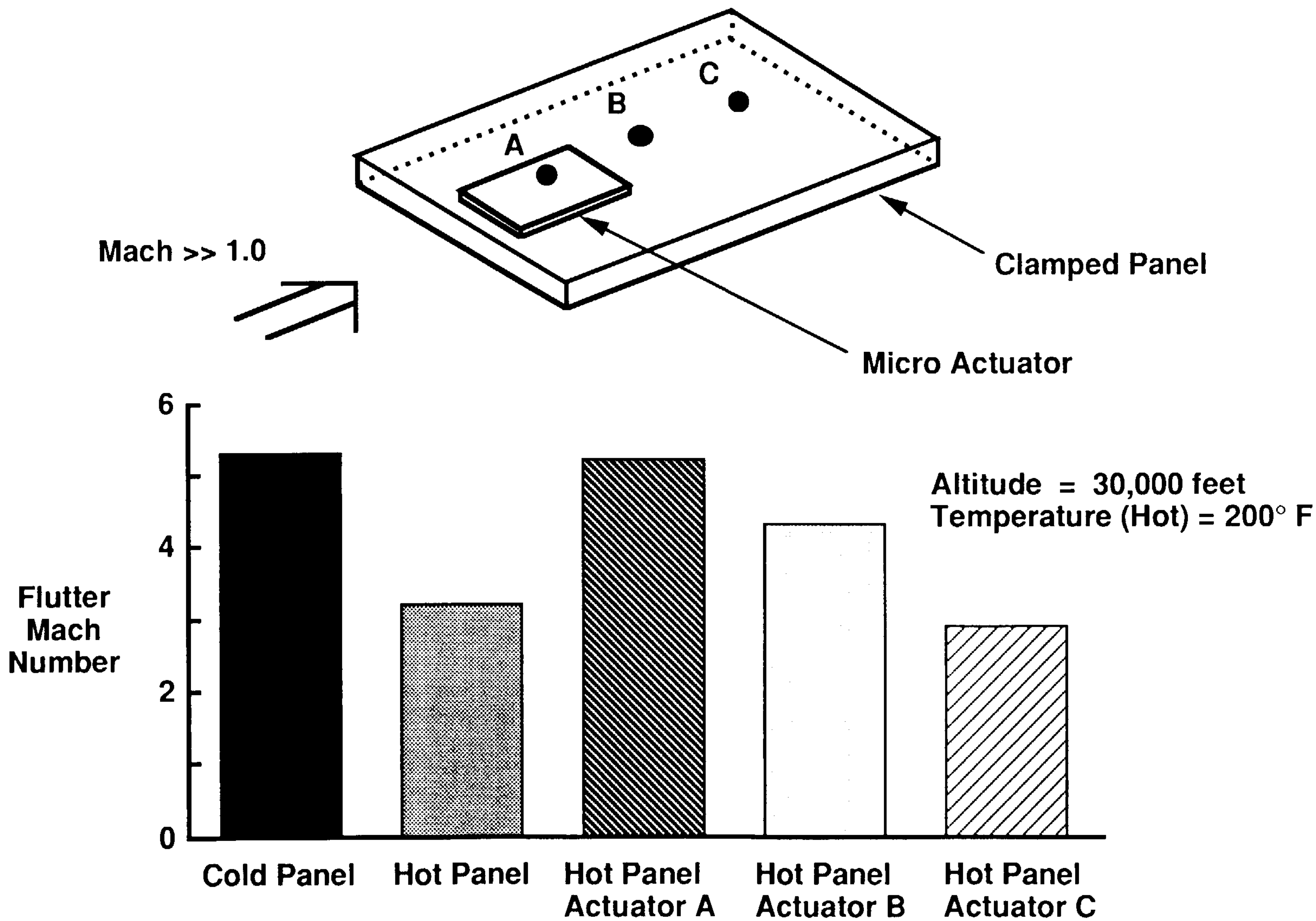


Figure 41 (b).

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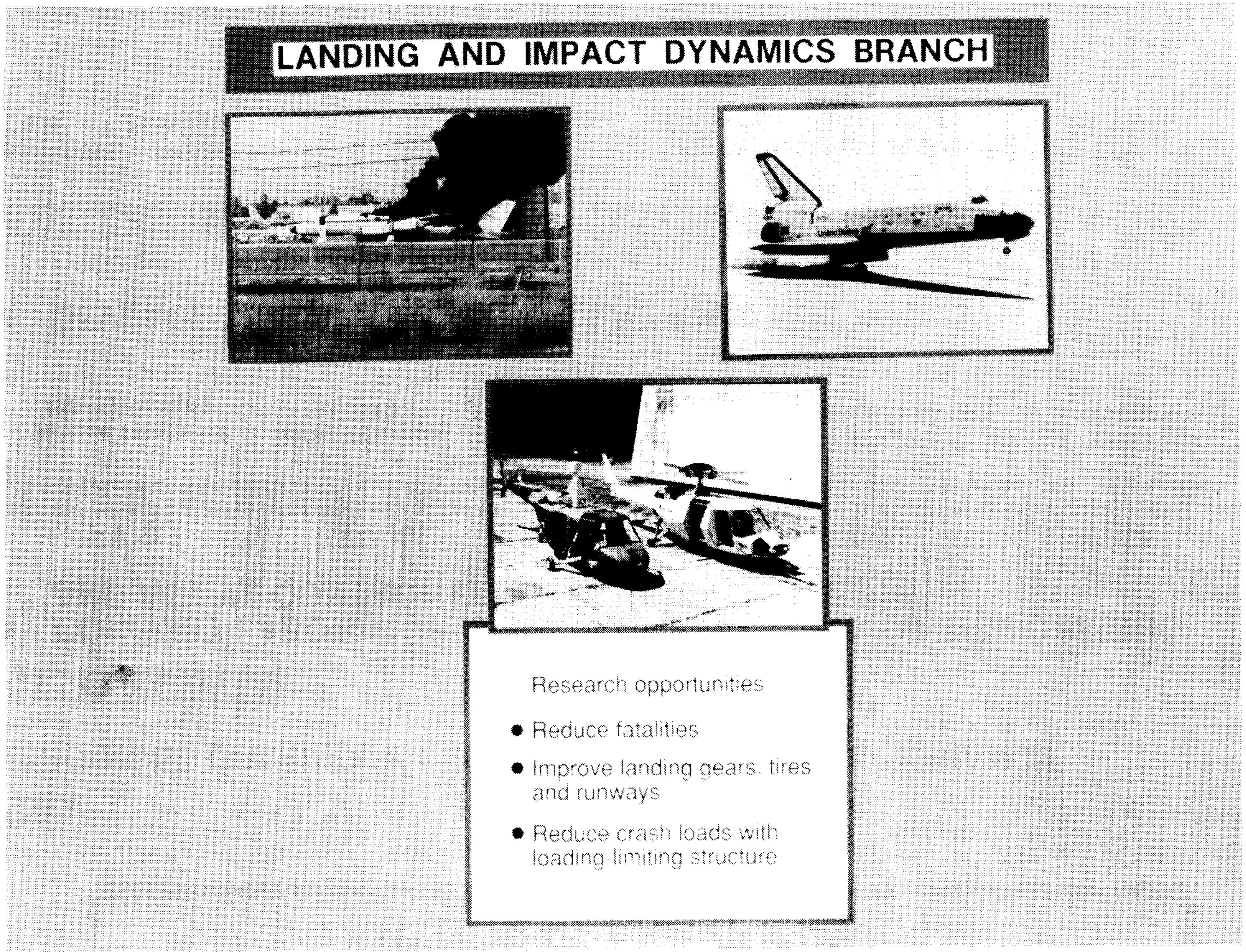

LANDING AND IMPACT DYNAMICS BRANCH
Research opportunities
• Reduce fatalities
• Improve landing gears, tires and runways
• Reduce crash loads with loading-limiting structure

Figure 42.

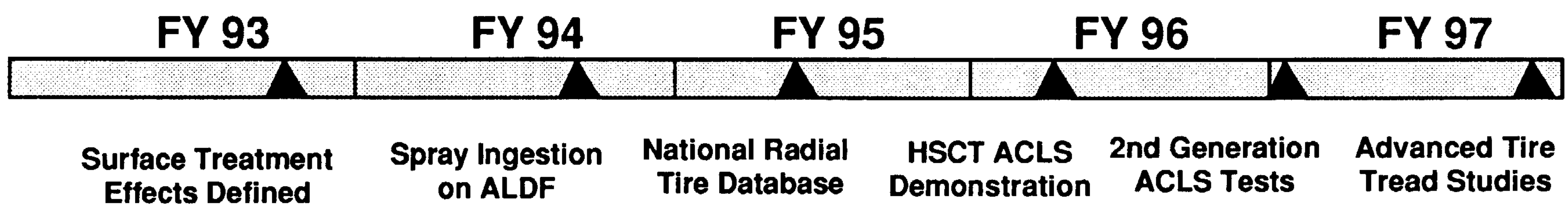
LANDING DYNAMICS
FUTURE PLANS (FY 93-97)

GOAL

ENHANCED GROUND HANDLING SAFETY AND PERFORMANCE

KEY OBJECTIVES

- CONDUCT LABORATORY AND ALDF TESTS OF NEW TIRE DESIGNS AND ACTIVE CONTROL LANDING GEAR CONCEPTS



- DEVELOP TIRE AND LANDING GEAR ANALYSIS TOOLS

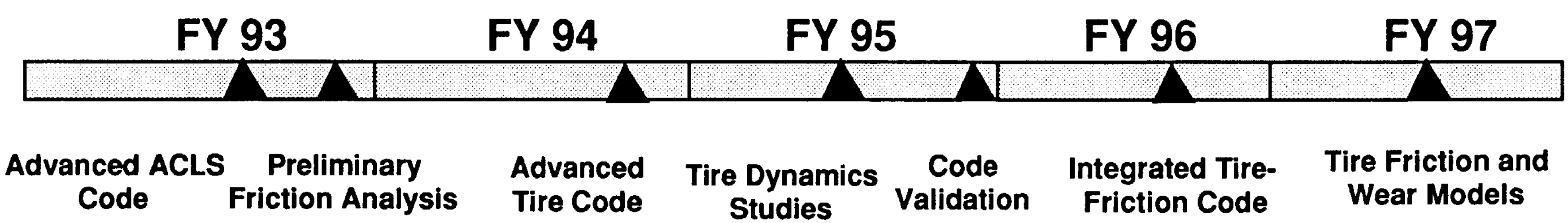


Figure 43 (a).

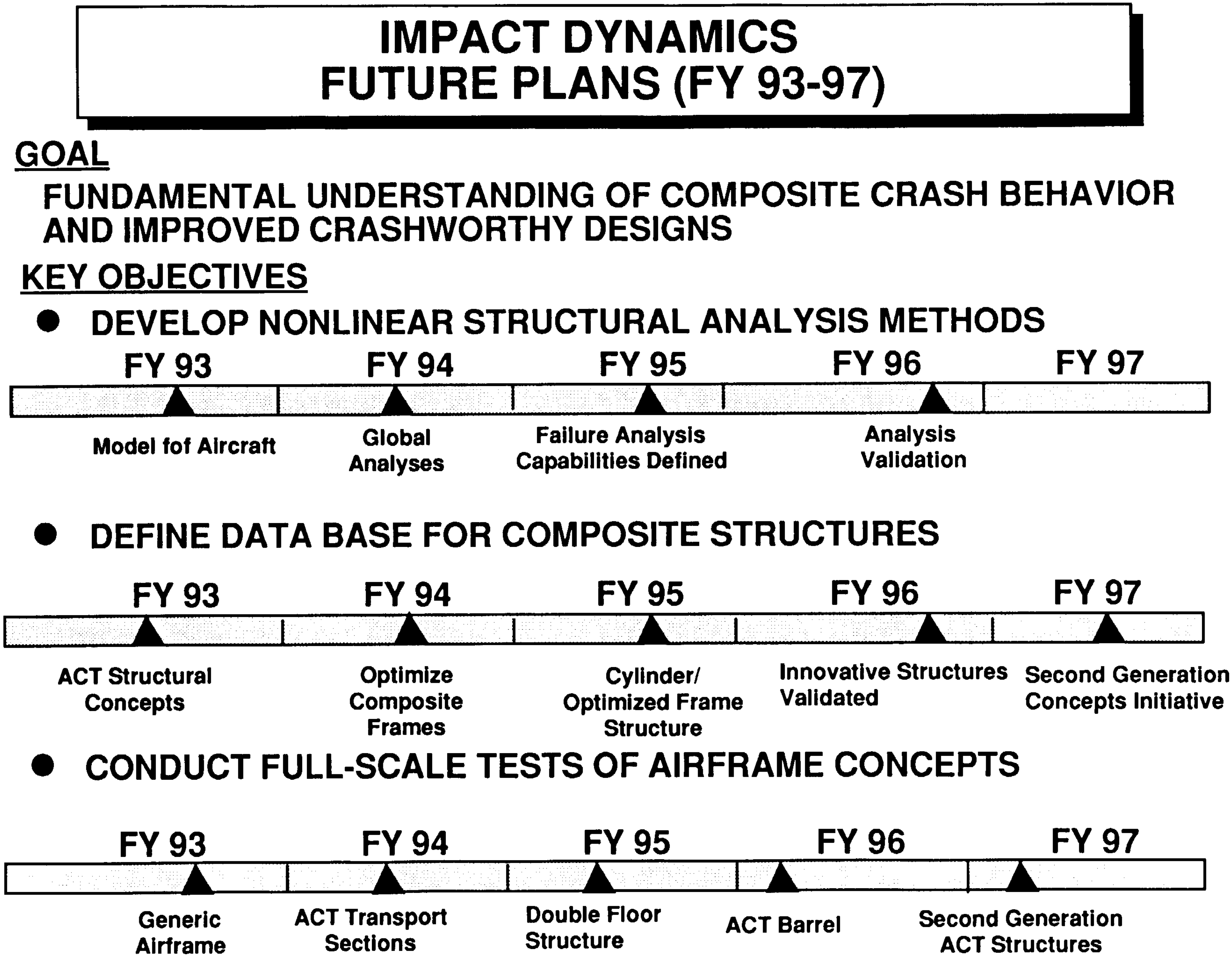

IMPACT DYNAMICS
FUTURE PLANS (FY 93-97)
GOAL
FUNDAMENTAL UNDERSTANDING OF COMPOSITE CRASH BEHAVIOR AND IMPROVED CRASHWORTHY DESIGNS
KEY OBJECTIVES
DEVELOP NONLINEAR STRUCTURAL ANALYSIS METHODS
FY 93
FY 94
FY 95
FY 96
FY 97
Model fof Aircraft
Global Analyses
Failure Analysis Capabilities Defined
Analysis Validation
DEFINE DATA BASE FOR COMPOSITE STRUCTURES
FY 93
FY 94
FY 95
FY 96
FY 97
ACT Structural Concepts
Optimize Composite Frames
Cylinder/ Optimized Frame Structure
Innovative Structures Validated
Second Generation Concepts Initiative
CONDUCT FULL-SCALE TESTS OF AIRFRAME CONCEPTS
FY 93
FY 94
FY 95
FY 96
FY 97
Generic Airframe
ACT Transport Sections
Double Floor Structure
ACT Barrel
Second Generation ACT Structures

Figure 43 (b).

ACCURATE STRUCTURAL FAILURE PREDICTION OF COMPOSITE FUSELAGE COMPONENTS UNDER CRASH LOADS--AN ANALYTICAL CHALLENGE

Huey D. Carden, Lisa E. Jones
Landing and Impact Dynamics Branch, SDyD
and Sotiris Kellas
Lockheed Engineering and Sciences Company

RTOP 510-02-12

Objective: To conduct experimental and analytical studies, as part of a composite impact dynamics research program, to generate a data base on the behavior of composite structures under crash loads. As part of this research, the determination of the effect of the floor vertical attachment position on the response and failure of generic composite fuselage frames has been performed.

Approach: Nonlinear finite-element models of a six-foot diameter composite fuselage frame were formulated with the DYCAST (Dynamic Crash Analysis of Structures) computer code. Static loads were applied to the frame/floor simulation to determine the load-deflection response and failure loads of the composite frames. Failure loads and strain distributions were determined from the finite-element models in which the location of the simulated floor was varied along the circumference of the frame.

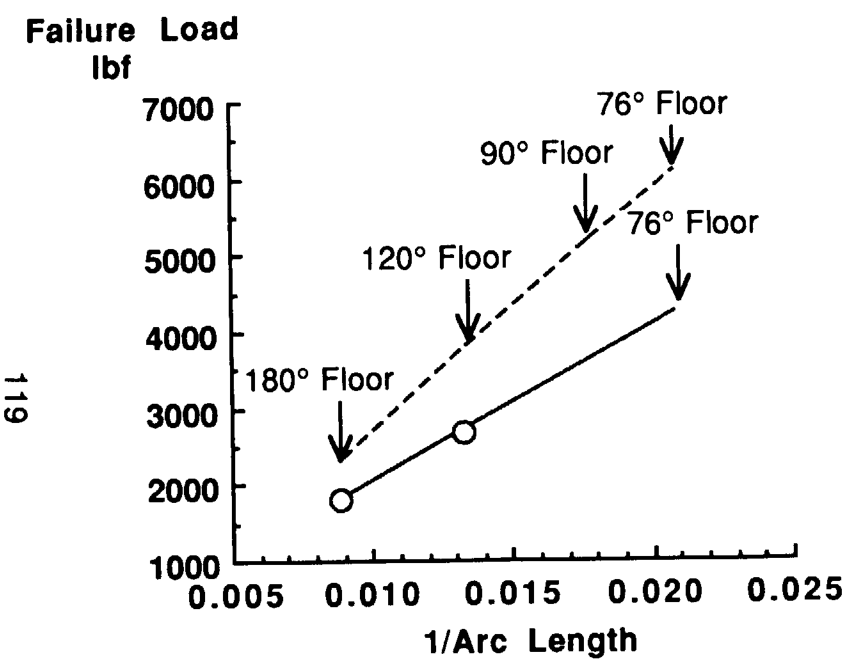
Accomplishment description: As shown in the left plot in the attached figure, the experimental static and analytical predictions of the failure load of a composite I-frame varies essentially linearly (for angles between 30° and 360°) as a function of 1/arc length of the lower portion of the frame. Failure load prediction was based on a maximum material strain failure criteria. As may be noted, the shorter frame segments required the highest loads to produce failure. Data in the figure indicate that although the correct trend of the failure behavior has been predicted , the magnitude of the predicted failure loads are much higher than the experimental loads. However, when the actual experimentally measured strain was used in the analysis at which the inner flange of a frame segment delaminated, the predicted and experimental values for failure loads and strain distributions (right plot in the attached figure) for all composite fuselage frames, are in excellent agreement.

Significance: Clearly, the identification of damage initiation is needed before adequate failure criteria can be formulated to predict failure loads in such relatively complex structure as a fuselage frame. Consequently, the results from the study indicate that new and innovative damage and failure monitoring criterion (covering the various potential composite failure modes) is needed in analytical code to allow more accurate predictions of the various damage/failure loads in crash situations on composite aircraft structural components.

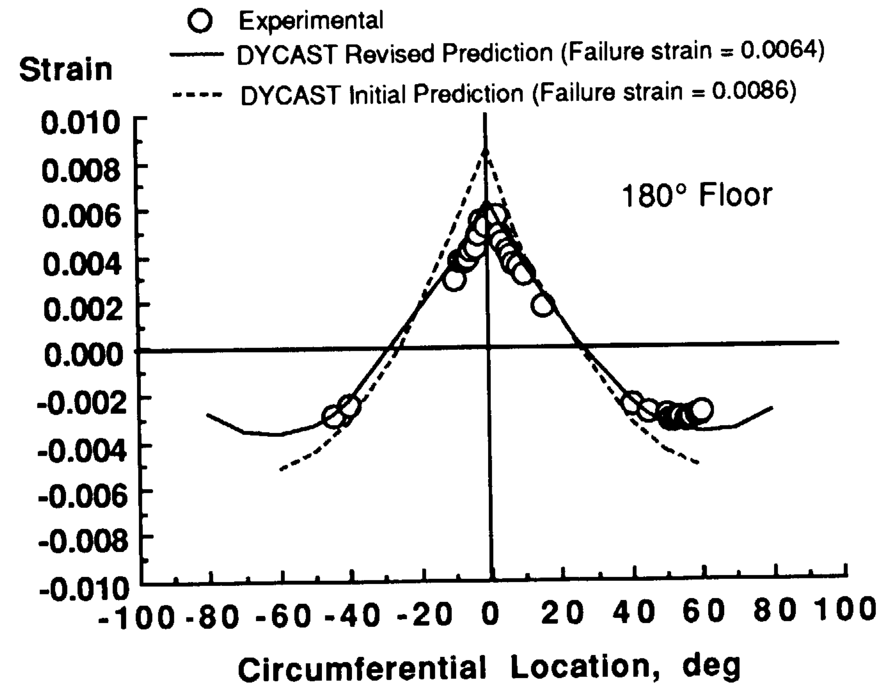
Fugure Plans: Conduct experimental and analytical studies to improve finite element code analytical capabilities to accurately prediction failure loads of composite aircraft fuselage components under crash loads.

Figure 44 (a).

ACCURATE STRUCTURAL FAILURE PREDICTION OF COMPOSITE FUSELAGE COMPONENTS UNDER CRASH LOADS--AN ANALYTICAL CHALLENGE



Failure Loads



Strain Distribution

Figure 44 (b).

CURVED BEAM FINITE ELEMENT DEVELOPED FOR OPTIMIZATION PROCESS OF COMPOSITES AIRCRAFT FUSELAGE FRAMES

Richard L. Boitnott, U.S.Army Aerostructures Directorate
Landing and Impact Dynamics Branch, SDyD
M. B. Woodson, E. R. Johnson, and R. T. Haftka
Department of Aerospace and Ocean Engineering
Virginia Polytechnic Institute and State University

RTOP 505-63-50

Objective: The purpose of this research is to maximize the energy absorption of thin-walled, open cross-section, curved composite beams under crash type loads through an optimization process.

Approach: Vlasov's curved thin-walled open cross-section beam theory is extended to accommodate beams constructed from laminated composite materials. The modified theory accounts for coupling effects present as a result of anisotropic material properties, as well as the effects of beam curvature and cross-section warping. Based on this extended theory, a finite element will be developed and used for analysis. Methods for predicting the progressive failure of open cross-section composite thin-walled beams will be developed and applied using results from the finite element analysis. Energy absorption under crash loads will be maximized by optimizing variables such as cross-section geometry, material, orientation, and lay-up.

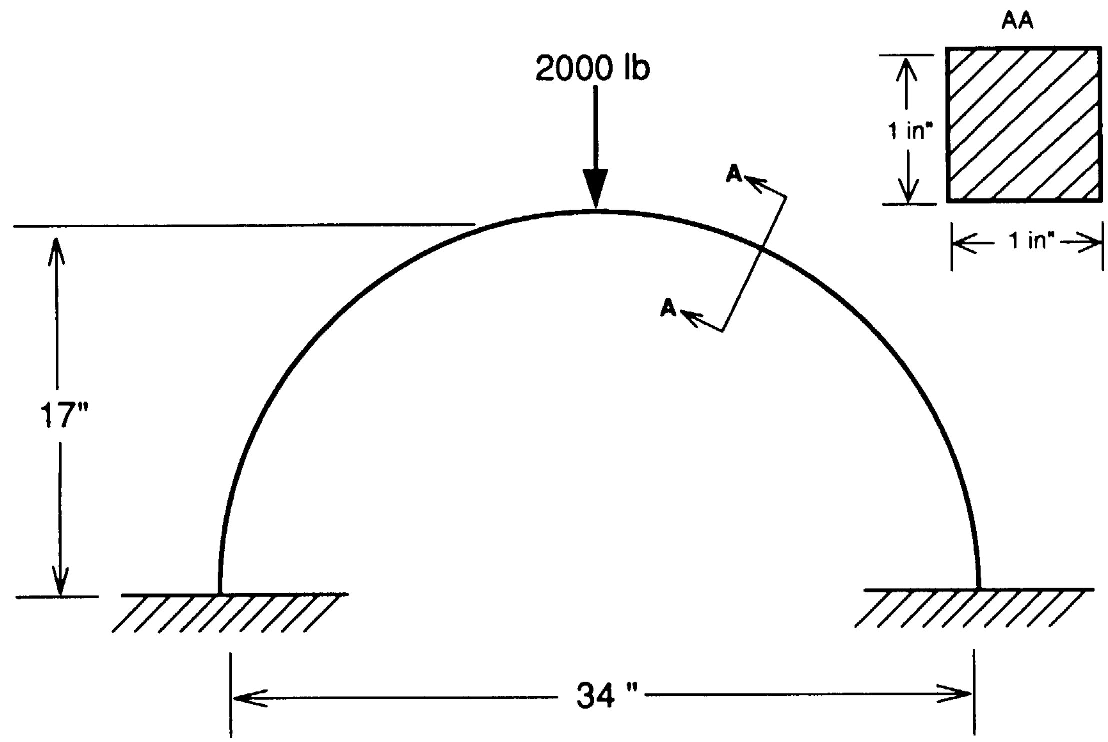
Accomplishment Description: Vlasov's open cross-section thin-walled curved beam theory has been extended to incorporate the constitutive relations of classical lamination theory. The theory was also modified to allow for an arbitrary origin of the cross-section coordinate system which permits more flexibility in the optimization process. Curved beam resultants are related to curved beam strains through a 5 x 5 matrix of 15 independent composite curved beam cross-section properties. A computer program was written and verified for calculating the section properties A displacement based curved beam finite element has been developed from the current theory using quintic interpolation polynomials for each independent displacement component. Interior degrees of freedom are condensed out, leaving 7 degrees of freedom for each of the 2 nodes of the element. The element has been incorporated into a modified version of the STAP finite element program. Preliminary convergence results in the figure with the finite beam element for a square section frame show excellent convergence comparison to existing curved beam studies reported by D.J. Dawes, Numerical Studies Using Circular Arch Finite Elements. Computers and Structures 4, pp. 729-740, 1974.

Significance: Vlasov's theory for open cross-section composite beams fills an analytical gap between existing beam theories for isotropic materials and the computationally expensive use of branched shell models for composite curved beams. The reduced analysis cost of composite beam theory makes this method more suitable for optimization and design work than shell analysis.

Future Plans: Continue verification of a finite element based on the composite curved beam open cross-section theory using branched shell finite element results as test cases.

Figure 45 (a).

CURVED BEAM FINITE ELEMENT DEVELOPED FOR OPTIMIZATION PROCESS OF COMPOSITE AIRCRAFT FUSELAGE FRAMES



CIRCULAR ARCH UNDER A CENTRAL LOAD

Number of elements for the half arch	Number of degrees of freedom	Center deflection (inches)	Error * %
1	1	0.14142135	0.07239
2	4	0.14152314	0.00046
3	7	0.14152380	0.00000

*Error with respect to the exact center deflection (0.1415238 inches)

Figure 45 (b).

ENERGY ABSORBING BEAM DESIGN FOR COMPOSITE AIRCRAFT SUBFLOOR

Huey D. Carden and Lisa E. Jones
Landing and Impact Dynamics Branch, SDyD

Sotiris Kellas
Lockheed Engineering and Sciences Company
Hampton, VA

RTOP 505-63-50

Objective: To examine the efficiency of energy absorbing replacement floor structural concepts for an existing all composite fuselage aircraft. The efforts are a continuation of previous research dealing with crashworthy metal aircraft subfloor structures.

Approach: The sine wave composite beam concept, shown at upper left, has been examined previously with encouraging results. Variations of the sine wave beam are being examined to determine the best retrofit subfloor structure that would provide the desired cushioning (less than 20 g of occupant load) at crush speeds of approximately 30 fps.

Accomplishment Description: A typical section of the composite fuselage with the original subfloor structure is shown in the center of the figure. As shown in the center figure, the four spars that support the seat rails are aluminum whereas the rest of the subfloor structure is graphite composite. Static tests of such a subfloor section have shown that the existing structure is too stiff and too strong for cushioning loads resulting from crash speeds in the neighborhood of 30 fps, as recommended by the Part 23 of the Federal Aviation Regulations. Thus, the program, using the building block approach as illustrated in the attached figure, is underway to design and test a composite sine wave beams retrofit subfloor structure that would provide the desired cushioning (less than 20 g of occupant load) at crush speeds of approximately 30 fps. In particular, the four aluminum spars, are to be replaced in the composite aircraft shown in the lower right of the figure.

Significance: With the existing aircraft subfloor design resulting in excessively high occupant loading, there is a need to provide innovative structural concepts which have some inherent, more efficient energy absorbing mechanism(s) in the subfloor design.

Future Plans: Conduct experimental static and dynamic tests to verify the sine wave beam concept which meets the requirements for energy absorption at reduced occupant loading for inclusion in the full-scale aircraft.

Figure 46 (a).

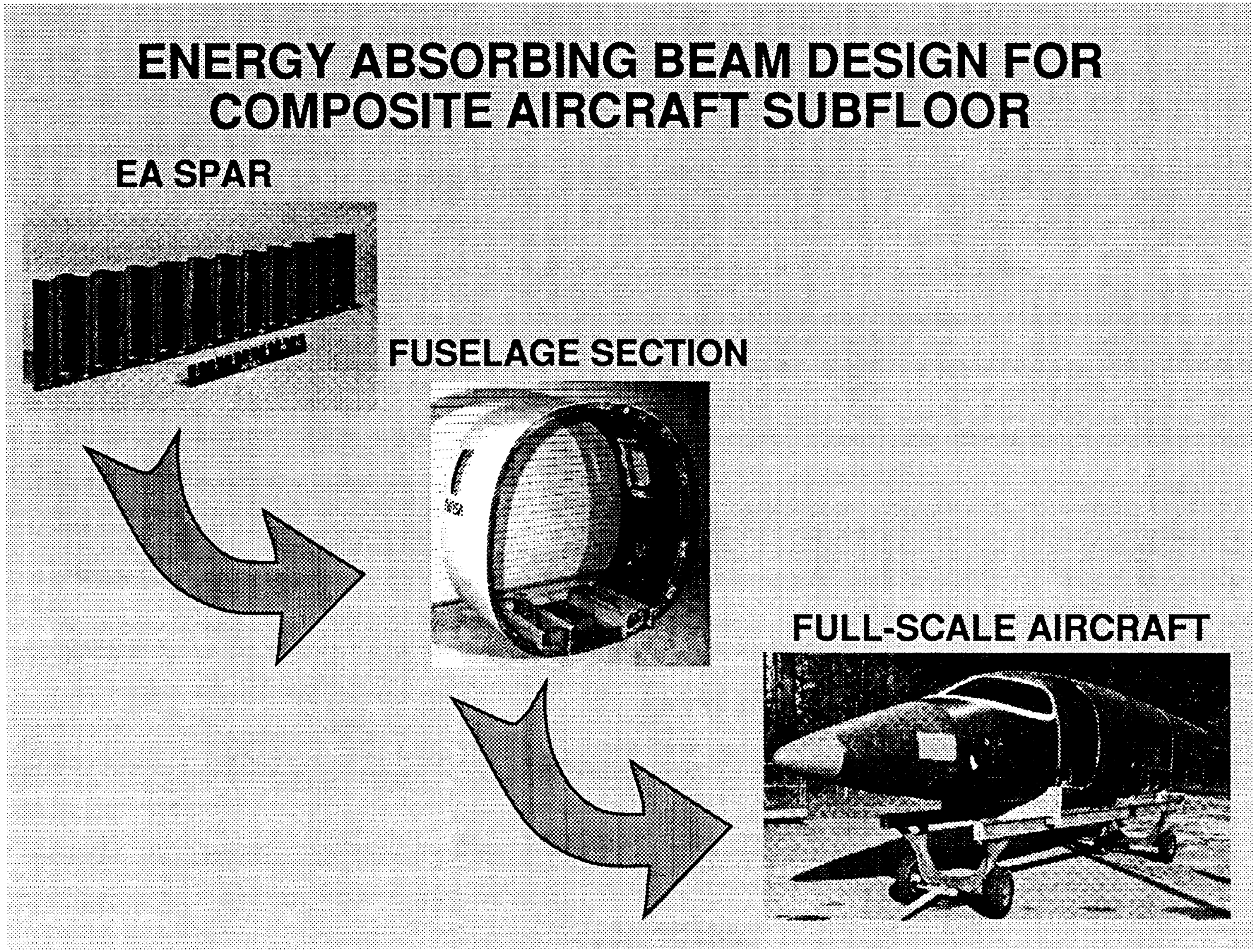

ENERGY ABSORBING BEAM DESIGN FOR
COMPOSITE AIRCRAFT SUBFLOOR
EA SPAR
FUSELAGE SECTION
FULL-SCALE AIRCRAFT

Figure 46 (b).

HIGH FAILURE LOADS OF METAL SUBFLOOR IN A COMPOSITE FUSELAGE EMPHASIZES NEED FOR ENERGY ABSORBING STRUCTURE

Huey D. Carden and Lisa E. Jones
Landing and Impact Dynamics Branch, SDyD
and
Sotiris Kellas
Lockheed Engineering and Sciences Company
Hampton, VA

RTOP 505-63-50

Objective: To study the loading behavior of an existing metal floor structural design in an aircraft concept. The study, which is a part of a wider full scale aircraft program, will examine composite replacement floor structures for the existing composite aircraft.

Approach: A typical section of a composite fuselage with the original subfloor structure is shown on the left of the figure. As shown in figure, the four spars that support the seat rails are aluminum whereas the rest of the subfloor structure is graphite composite. Static tests of such a subfloor section of the existing structure have been conducted to assess the strength of the "as designed" floor relative to cushioning loads from crash speeds in the neighborhood of 30 fps, as recommended by the Part 23 of the Federal Aviation Regulations.

Accomplishment Description: Static test results of the a subfloor section, shown at the right of the figure, indicate that the existing structure is too stiff and too strong for cushioning loads resulting from crash speeds in the neighborhood of 30 fps, as recommended by the Part 23 of the Federal Aviation Regulations. The combination of stiff and brittle composite frames with aluminum spars results in high failure loads but with little energy absorption. Initiation loads in excess of 650 lb/inch (per seat position) and crushing loads varying between 75 to 150 lb per running inch of fuselage length per spar (four spars) have been recorded as opposed to a desired sustained crushing load of about 200 lb/in per spar. Therefore, a retrofit composite sine wave beam subfloor structure that would provide the desired cushioning (less than 20 g of occupant load) at crush speeds of approximately 30 fps are toreplace the four aluminum spars, shown in the fuselage section of the figure.

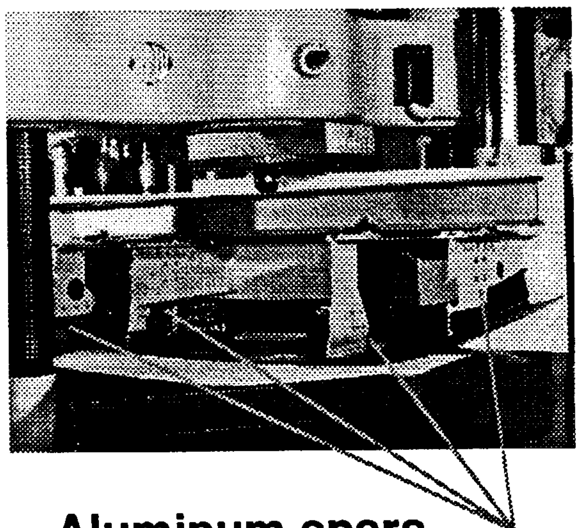
Significance: Clearly the high loads generated by the original metal floor design in the composite fuselage aircraft concept is much too high and energy absorption too low for potential occupant survivability in a crash situation. Since the composite frames are discontinuous in the section as opposed to being complete in the aircraft, the loads for the floor section most probably represent a lower bound.

Future Plans: A wider full scale aircraft test program will examine the efficiency of replacement floor structural concepts to provide inherent energy absorption capabilities for the existing all composite fuselage aircraft. The efforts are a continuation of previous research dealing with crashworthy metal aircraft subfloor structures.

Figure 47 (a).

HIGH FAILURE LOADS OF METAL SUBFLOOR IN COMPOSITE FUSELAGE EMPHASIZES NEED FOR ENERGY ABSORBING STRUCTURE

Experimental Set-Up	Floor Load Behavior



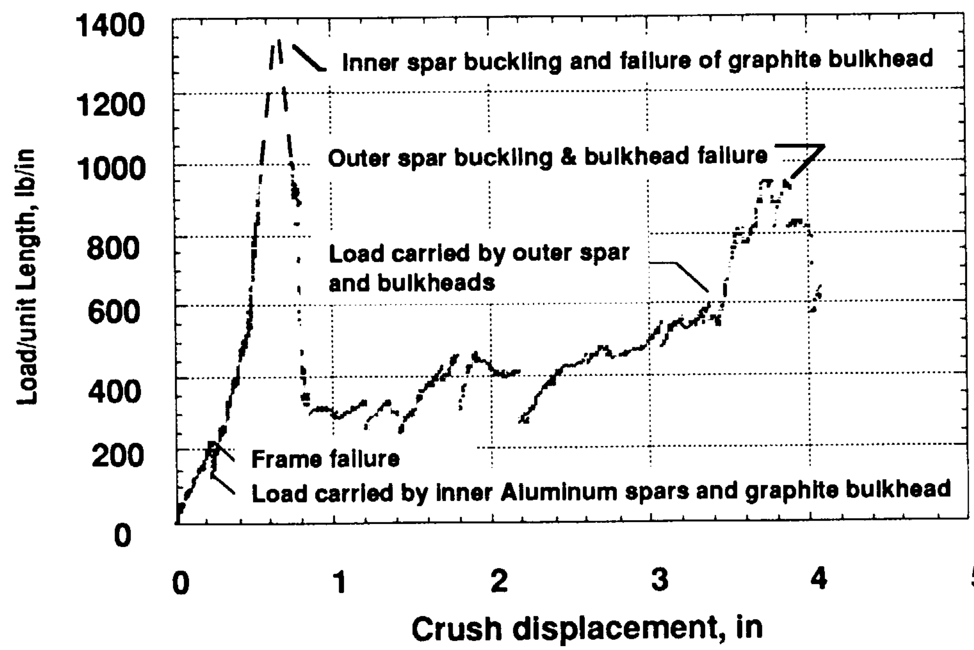


Figure 47 (b).

NEW TIRE-CONTACT-FRICTION ALGORITHM CORRELATED WITH SPACE SHUTTLE NOSE-GEAR TIRE EXPERIMENTAL RESULTS

John A. Tanner
Landing and Impact Dynamics Branch
RTOP 505-63-10

Research Objective: To develop a tire-contact-friction algorithm to determine tire response to combined inflation pressure and static vertical loading conditions, including the prediction of normal and frictional forces in the tire-runway contact zone (or footprint area).

Approach: The contact friction algorithm is incorporated into a mixed formulation, two-dimensional shell finite-element model that includes the effects of transverse-shear deformations, laminated anisotropic material response, and nonhomogeneous shell characteristics. The contact algorithm is based on a perturbed Lagrangian formulation and uses the preconditioned conjugate gradient iteration procedure. The contact algorithm incorporates a modified version of the Coulomb friction law wherein the friction coefficient at the onset of sliding is different from that during sliding. The algorithm includes the effects of energy dissipated within the sliding portion of the contact zone.

Accomplishment Description: Numerical studies have demonstrated that the contact friction algorithm is robust enough to handle the range of friction coefficients normally associated with aircraft tire applications. An illustrative result is shown in the figure which presents measured and calculated lateral friction load intensity distributions and footprint shapes for the Space Shuttle nose-gear tire. These results are for a static vertical load of 15 000 pounds for the tire on a dry runway. The measured footprint and laternal friction loads data are shown at the top; the corresponding calculated results are shown at the bottom. The measured and calculated footprint shapes are very similar. Both the measured and calculated lateral friction load intensities reach their respective maximum magnitudes in the lateral extremities of the tire footprint. This trend is more pronounced for the calculated results than for the measured values. Both measured and predicted lateral friction load intensities exhibit bands of alternating positive and negative friction values across the width of the tire footprint.

Significance: The tire-contact-friction algorithm will be a valuable analysis tool for developing a fundamental understanding of the friction and wear mechanisms that exist in the tire-runway interface.

Future Plans: The contact friction algorithm will be incorporated into the computer codes that generate tire sensitivity coefficients to define the effects of tire geometry and material property variations on normal load and friction distributions. The algorithm will also be extended to handle rolling contact.

Figure 48 (a).

NEW TIRE-CONTACT-FRICTION ALGORITHM CORRELATED WITH SPACE SHUTTLE NOSE-GEAR TIRE EXPERIMENTAL RESULTS

Tire Load, 15 000 pounds; Inflation Pressure, 300 psi

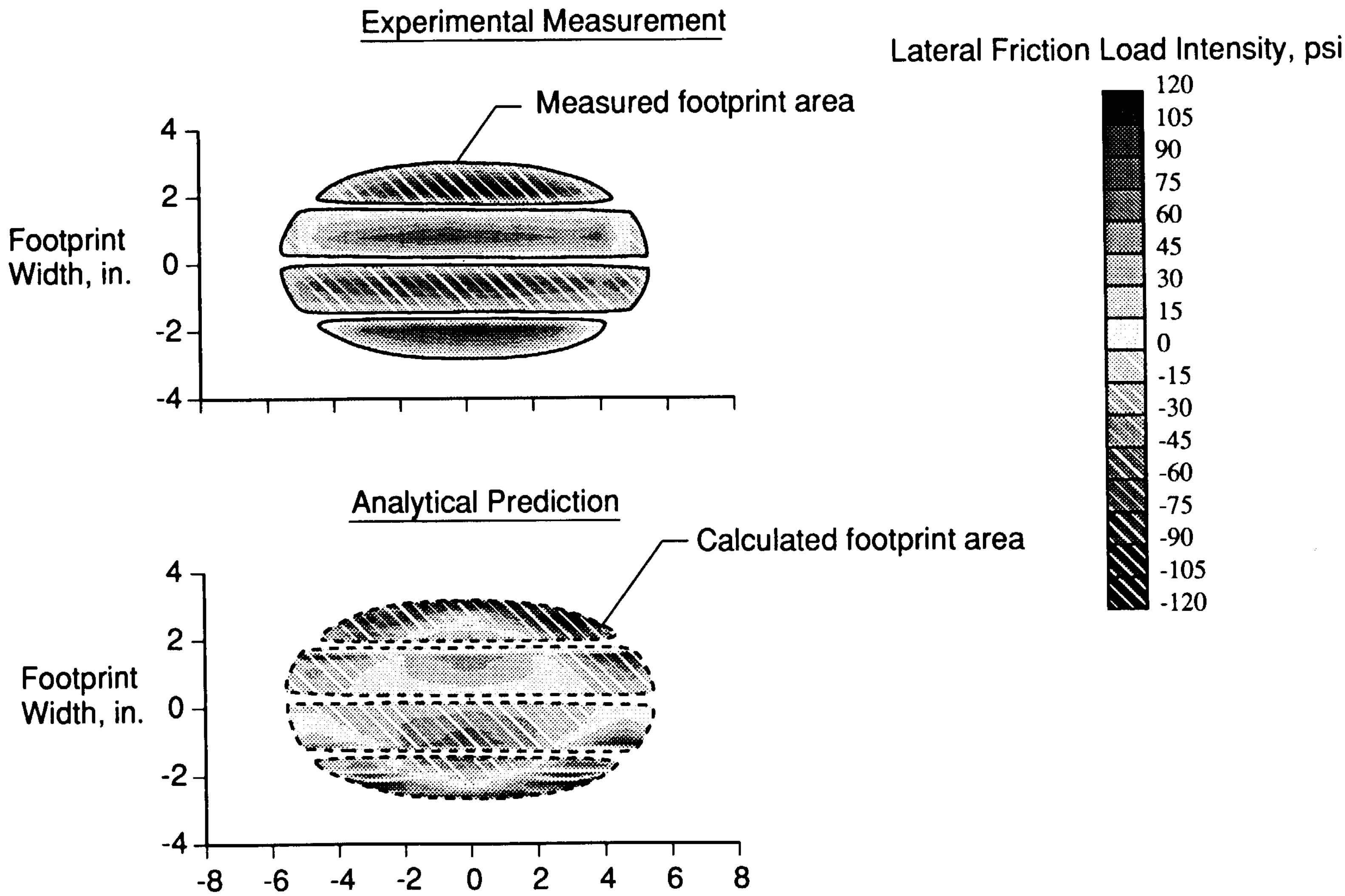


Figure 48 (b).

F-4 BIAS-PLY AND RADIAL-BELTED TIRE STIFFNESS VALUES DEFINED

Pamela A. Davis
Landing and Impact Dynamics Branch, SDyD
RTOP 505-63-10-02 Code

Research Objective: The research objective is to study the mechanical properties of an F-4 main landing gear tire (30X11.5-14.5) of a radial-belted design and compare those properties to those of the same size bias-ply tire.

Approach: Two different F-4 tire designs are being tested at the Aircraft Landing Dynamics Facility (ALDF). The two tire designs are being subjected to vertical, lateral, and fore-and-aft tests under static and free-vibration conditions to define the mechanical properties of the tires.

Accomplishment Description: The 30X11.5-14.5 tires in a radial-belted and bias-ply design have been tested in the lab at the ALDF. Static vertical, lateral, and fore-and-aft tests have been conducted on both tire designs. The fore-and-aft stiffness characteristics of the two tire types tested are shown in the attached figure. These tires were tested at 25 000 lb vertical load and 3000 lb fore-and-aft load. The fore-and-aft stiffness values of the radial tire were 26 to 37 percent less than the values obtained for the bias-ply tire. These lower stiffness values of the radial-belted tire could introduce a lag between the braking effort and the ground reaction which could effect the dynamics of the antiskid braking system designed for this size bias-ply tire. Free-vibration lateral and fore-and-aft tests have been conducted on both tire designs as well. These tests were conducted to obtain a better indication of tire behavior under braking conditions.

Significance: The information shown in the attached figures will help to establish a national database for radial-belted aircraft tires that will be used to compare their mechanical properties and frictional characteristics with those of bias-ply tires.

Future Plans: Braking and cornering tests will be conducted on a non grooved runway under dry and wet surface conditions at speeds up to 160 knots in order to further define the braking and friction characteristics of the two tire designs. This information will be documented in a reference publication to be used as a landing gear design guide.

Figure 49 (a).

F-4 BIAS-PLY AND RADIAL-BELTED TIRE STIFFNESS VALUES DEFINED

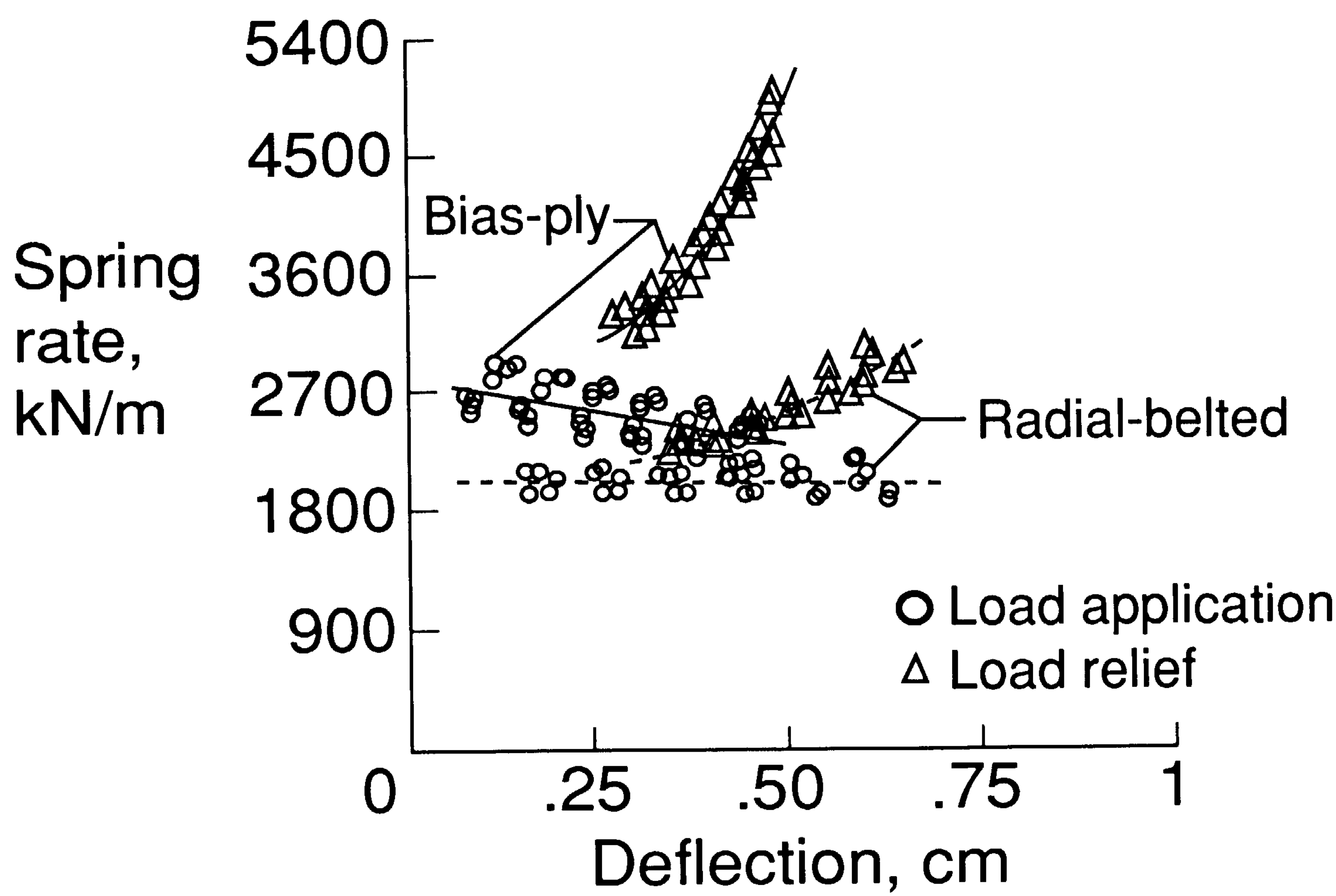


Figure 49 (b).

LANDING SYSTEMS RESEARCH AIRCRAFT DEVELOPED

Robert H. Daugherty
Landing and Impact Dynamics Branch, SDyD
RTOP 505-63-10-02

Research Objective: To conduct tests using full-scale orbiter main and nose gear tires and hardware under realistic speeds, loads, yaw angles, distances, and runway surfaces.

Approach: A NASA Dryden Convair 990 aircraft was modified to accept a test system located in a hole placed between the aircraft's main landing gear as shown in the top of the figure. The hole necessitated building a complicated, three-dimensionally curved set of auxiliary keels to spread the aircraft main keel loads around the center section of the aircraft belly. The thick aircraft center keel was then cut away from the test gear area. The lower part of the figure shows a perspective view of the test gear apparatus attached to the airplane. It consists of a set of trusses attached to the wing spars that support up to 250,000 lb of vertical load applied to the test gear by a set of hydraulic actuators. The test gear, which can be either of the orbiter main or nose struts or a variable yaw fixture for a single tire, is attached to a pallet which is part of a four-bar linkage system that articulates and applies load to the test tire. Any combination of load, yaw angle, speed, and distance profile can be tested using the system at any site the aircraft can land. The aircraft can land at speeds up to 230 kt, with the test gear load and yaw angle computer-controlled. All tire forces can be measured and recorded for immediate analysis.

Accomplishment Description: Modifications to the Convair 990 aircraft are essentially completed and it is now referred to as the Landing Systems Research Aircraft (LSRA). A Flight Readiness Review (FRR) has been conducted and a functional check flight is scheduled for November 1992. Tests will be conducted at Edwards Air Force Base first to evaluate the test system and then the aircraft will be ferried to Kennedy Space Center (KSC) for wear and force testing at that site to demonstrate the crosswind capability of the modified tire.

Significance: Every tire test facility built in this country to date has some significant drawback in terms of completeness; i.e. the ALDF has short distances and low loads, WPAFB dynamometers have wrong runway surface and curvature, etc. The LSRA design allows tests where each of the important tire testing parameters is duplicated without compromise. This facility will allow comparisons between real-life and dynamometer tests and most likely will change how the tire community conducts tire tests in the future. Orbiter flight rules concerning crosswind are also likely to change based on these tests.

Future Plans: Initial data flights will begin in January 1993 and KSC tests should begin in late February 1993. Testing should last about eight months, with full-scale orbiter strut failure tests a possible follow-on test series if funded.

Figure 50 (a).

LANDING SYSTEMS RESEARCH AIRCRAFT DEVELOPED

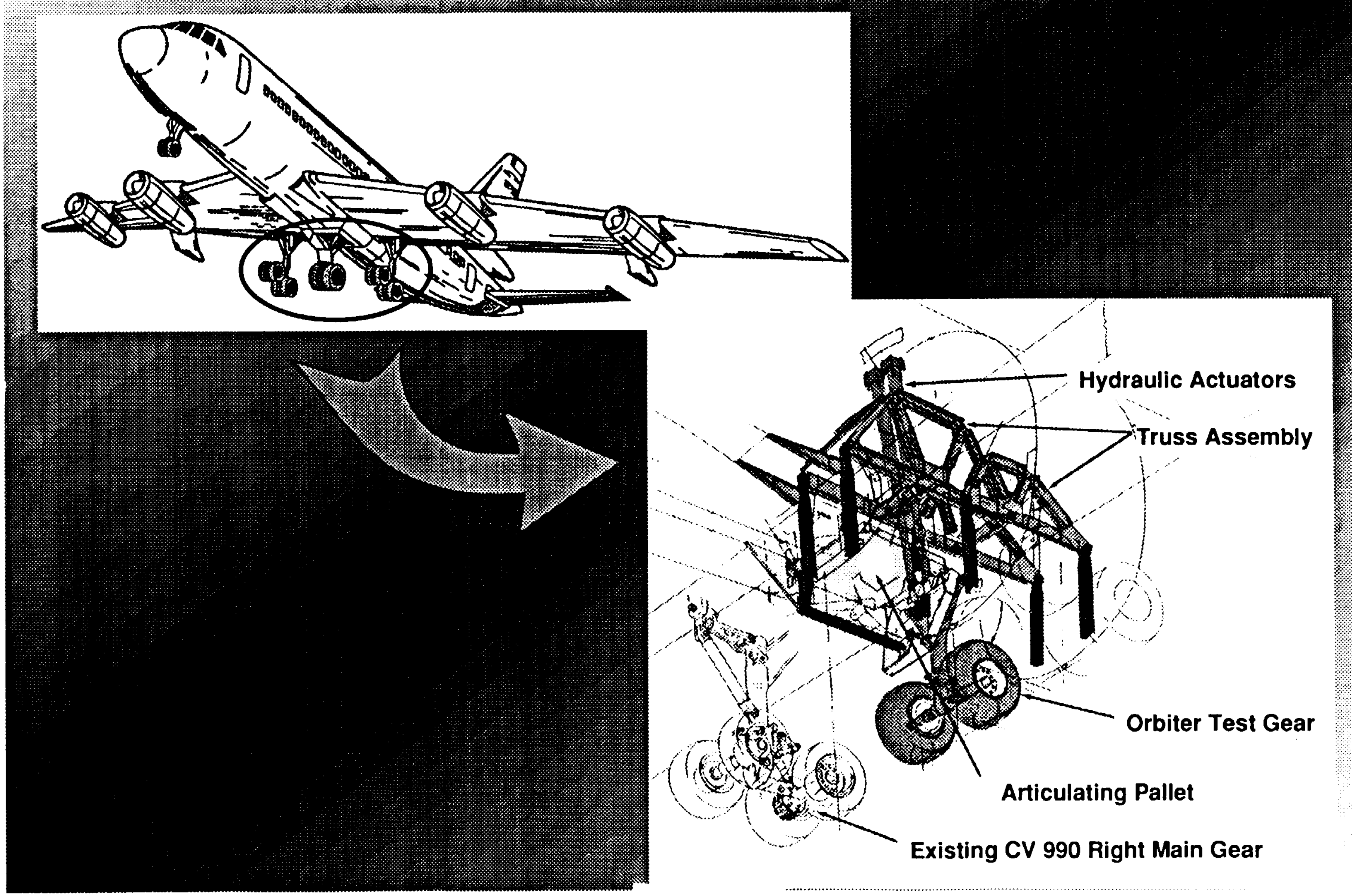


Figure 50 (b).

CORNERING PERFORMANCE OF 40 X 14 BIAS-PLY AND RADIAL-BELTED TIRES EVALUATED ON WET CONCRETE PAVER BLOCK SURFACES

Thomas J. Yager
Landing and Impact Dynamics Branch

RTOP 505-63-10-53

Research Objective: The research objective is to study aircraft tire friction performance on different concrete paver block surfaces for possible applications at airport facilities.

Approach: Two different paver block surfaces have been installed at the Aircraft Landing Dynamics Facility (ALDF). Cornering or side force friction coefficient data developed by bias-ply and radial-belted 40 X 14 aircraft tires have been collected under dry and wet surface conditions at speeds up to 160 knots and a range of yaw angles from 0 to 16 degrees. These tests were performed at the same rated load and inflation pressure for both tires. These tires are used on the main-gears of the Boeing B-727 and the McDonnell Douglas DC-9 transport aircraft.

Accomplishment Description: The friction characteristics of two concrete paver block designs, hexagonal and uni-anchorlock, and a conventional smooth concrete surface, have been evaluated on ALDF using both types of test tires . The variation in side force friction coefficient with yaw angle measured at 100 knots on these three test surfaces under wet conditions is shown for each tire in the attached figure. The paver block surfaces produced higher side force friction values than the smooth concrete with both test tires under these wet conditions. These results indicate that for aircraft ground steering maneuvers on wet pavements, the paver blocks would provide more friction between tire and surface than the conventional smooth concrete surface.

Significance: The information shown in the attached figure will help to identify the friction capability of different interlocking paver block designs for possible airport applications. These findings may eventually contribute to improving aircraft safety during ground operations under adverse weather conditions.

Future Plans: Future tests will be conducted on additional concrete paver block designs and a transversely grooved conventional concrete surface under dry and wet conditions using 40 X 14 aircraft tires. This information will be documented in conference papers and a NASA reference publication for use by airport/aircraft industry personnel and paver block manufacturers.

Figure 51 (a).

CORNERING PERFORMANCE OF 40 X 14 BIAS-PLY AND RADIAL-BELTED TIRES EVALUATED ON WET CONCRETE PAVER BLOCK SURFACES

VERT. LOAD, 111-124 kN (25-28 KLB); INFL. PRESSURE, 1.17 MPa (170 PSI)
SPEED, 100 KNOTS

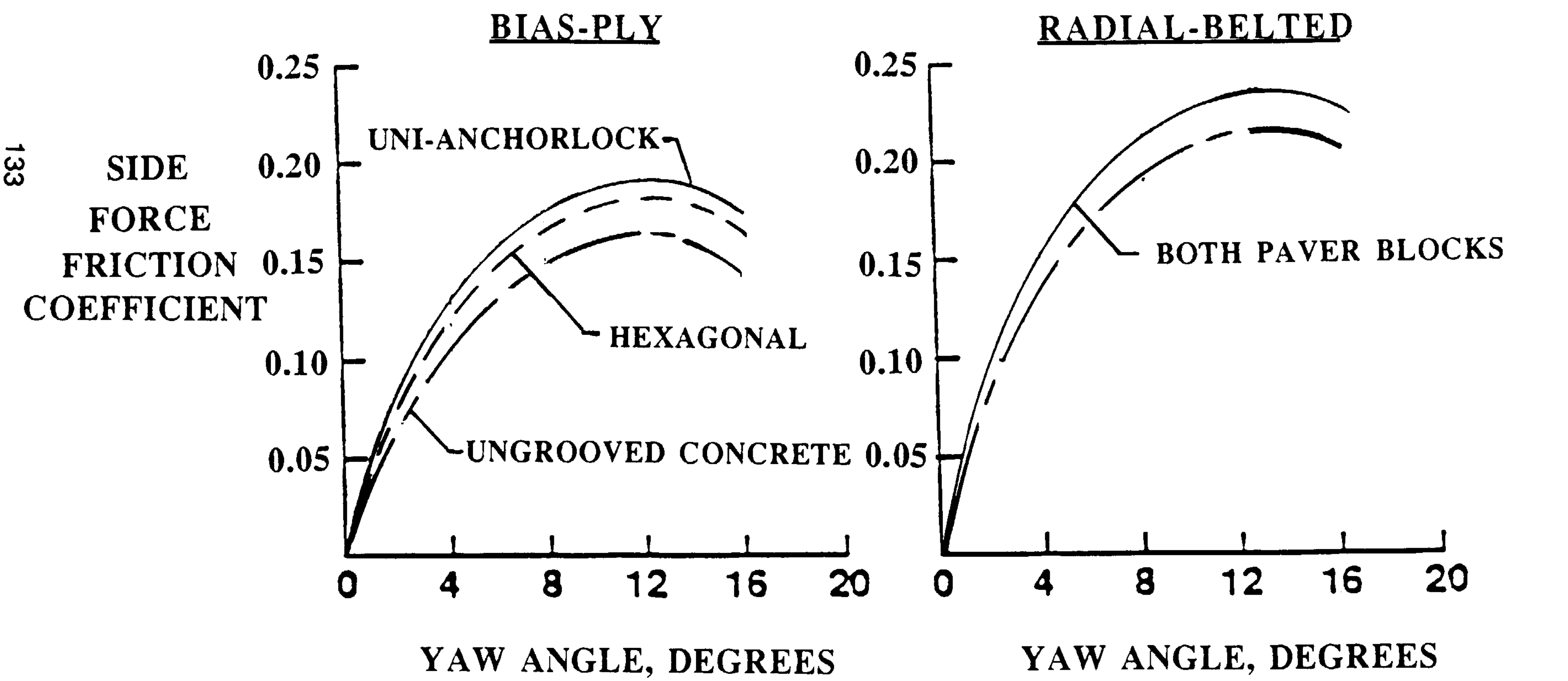


Figure 51 (b).

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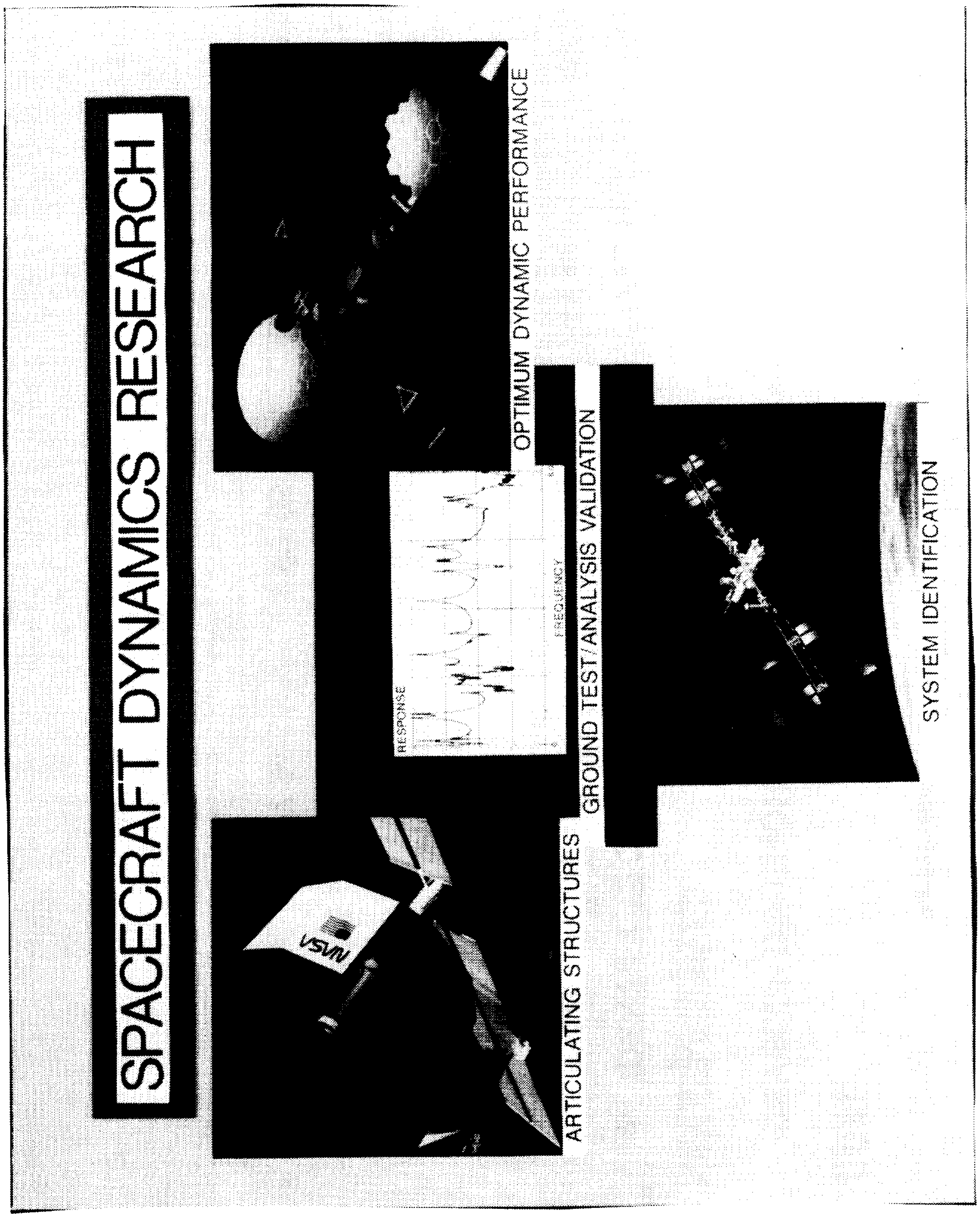

SPACECRAFT DYNAMICS RESEARCH
OPTIMUM DYNAMIC PERFORMANCE
RESPONSE
FREQUENCY
GROUND TEST/ANALYSIS VALIDATION
ARTICULATING STRUCTURES
NASA
SYSTEM IDENTIFICATION

Figure 52.

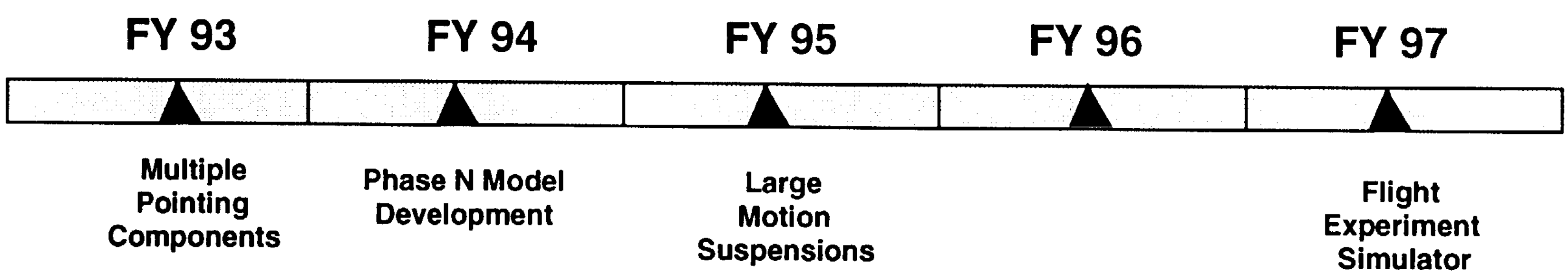
SPACECRAFT DYNAMICS FUTURE PLANS (FY 93-97)

GOAL

DEVELOP CSI GROUND TEST TECHNOLOGY

KEY OBJECTIVES

- IDENTIFY TECHNOLOGY ISSUES USING GROUND BASED TESTBEDS



- VALIDATE CONTROL METHODS FOR FLEXIBLE SPACECRAFT

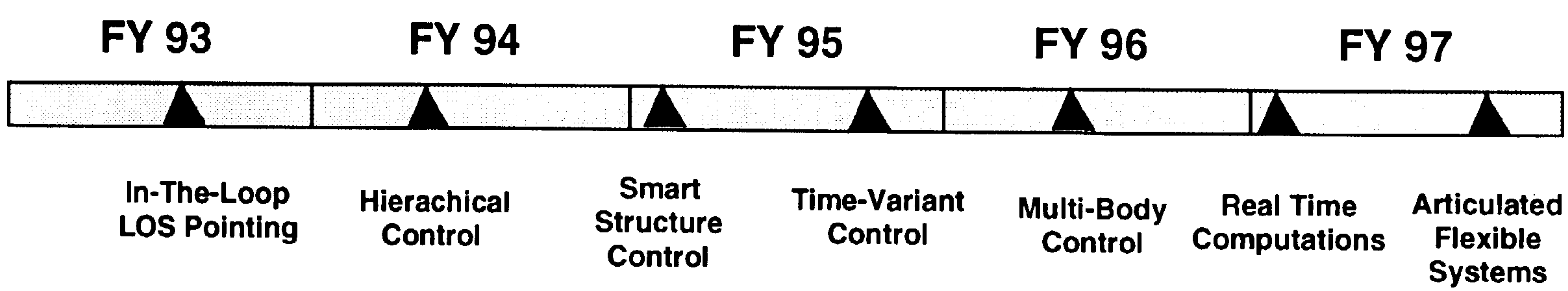


Figure 53 (a).

SPACECRAFT DYNAMICS FUTURE PLANS (FY 93-97)

GOAL

DEVELOP VALIDATED TECHNOLOGY FOR PREDICTION OF ON-ORBIT STRUCTURAL DYNAMICS OF FUTURE SPACECRAFT MISSIONS

KEY OBJECTIVES

- SPACECRAFT GROUND VERIFICATION METHODS VIA SCALE-MODELS

FY 93 | FY 94 | FY 95 | FY 96 | FY 97

- FY 93: Preintegrated Truss Design & Component Prototypes
- FY 94: Preintegrated Truss Configuration
- FY 95: Full Scale Test & Analysis Comparisons/Update
- FY 96: CMG & Alpha Control Capability
- FY 97: Revised Verification Procedures

- FLEXIBLE SPACECRAFT ON-ORBIT VERIFICATION METHODS

FY 93 | FY 94 | FY 95 | FY 96 | FY 97

- FY 93: SSF Flight Test Supplement Plan
- FY 94: High-Fidelity Simulation
- FY 95: Real-Time Flight Test Operations Sim
- FY 95: Data Analysis Software & Plan
- FY 96: Flight Tests Begin
- FY 97: Flight Data & Verification Accuracy Assessment

Figure 53 (b).

SPACECRAFT DYNAMICS
FUTURE PLANS (FY 93-97)

GOAL

DEVELOP ADVANCED METHODS FOR IDENTIFICATION, ANALYSIS, AND CONTROL OF COMPLEX FLEXIBLE SPACECRAFT DYNAMICS

KEY OBJECTIVES

- **MULTI-BODY AND ARTICULATED SYSTEM ANALYSIS & CONTROL**

FY 93	FY 94	FY 95	FY 96	FY 97
7-D-of-F Flexible Manipulator Lab Model	Assembly Dynamics Lab Experiment	Flexible Component Assembly	Deployable Spacecraft Modules	

- **SYSTEM IDENTIFICATION & ANALYSIS METHODS**

FY 93	FY 94	FY 95	FY 96	FY 97
Damage Detection/ Model Updating	Neural Networks	ID of Highly Damped Structures	Transient On-Line System ID	Nonlinear System ID

Figure 53 (c).

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PASSIVE DAMPING STABILIZATION OF ACTIVE CONTROLLER

W. Keith Belvin
Spacecraft Dynamics Branch

Eric Schmitz and Ken Richards
Martin Marietta Corporation

RTOP 590-14-61

Objective: To reduce spacecraft vibrational jitter and thus improve the quality of science data imaged from space, active control systems are being developed for future spacecraft. The active systems are highly adaptable to changes in the spacecraft over its lifetime. However, to maintain good stability margins in the active control systems, adequate damping must exist in the spacecraft. This work is aimed at developing a passive damping treatment that will provide sufficient damping for the active control system.

Approach: To augment the structural damping, a vicsoelastic strut was designed for the Phase 1 & 2 CSI Evolutionary Models (CEM) to augment the inherent structural damping. An active control system was used to determine what level of passive damping would be required. The desired damping level could then be obtained by selecting the number and location of viscoelastic struts

Accomplishment: As shown in the attached figure, a constrained layer damping design was developed. Twelve (12) truss struts were fabricated to achieve 1.2 percent damping in a vibration mode involving bending of the CEM laser tower appendage. Dyad 606 viscoelastic material was chosen for its high stiffness properties and because of its good loss factor at the temperature of the laboratory. The attached figure shows three time responses of acceleration measured on the CEM testbed. The open-loop response has no active control system or passive damping treatment. This figure shows the structural response due to a periodic disturbance lasting for seven seconds and subsequently removed. The active control figure shows the CEM response for a control system activated at ten seconds. The response initially decays but then grows due to an unstable mode of the laser tower. The passive and active figure shows the CEM response for the same active system but with 12 viscoelastic struts placed at the base of the laser tower. The figure shows that the passive damping treatment stabilized the otherwise unstable active control system.

Significance: This study has showed the importance of adding passive damping treatments to structures when active control systems are used. Modeling of the viscoelastic material was validated through these tests such that design tools are now in-hand. In addition, fabrication procedures have been developed to accurately build constrained layer damping treatments.

Future Plans: Plans are to construct 100 passive damping struts for the Phase 2 CEM to find an optimal balance between active and passive control of spacecraft. In addition, this number of struts will permit validation of optimal strut placement algorithms.

Figure 54 (a).

PASSIVE DAMPING STABILIZATION OF ACTIVE CONTROLLER

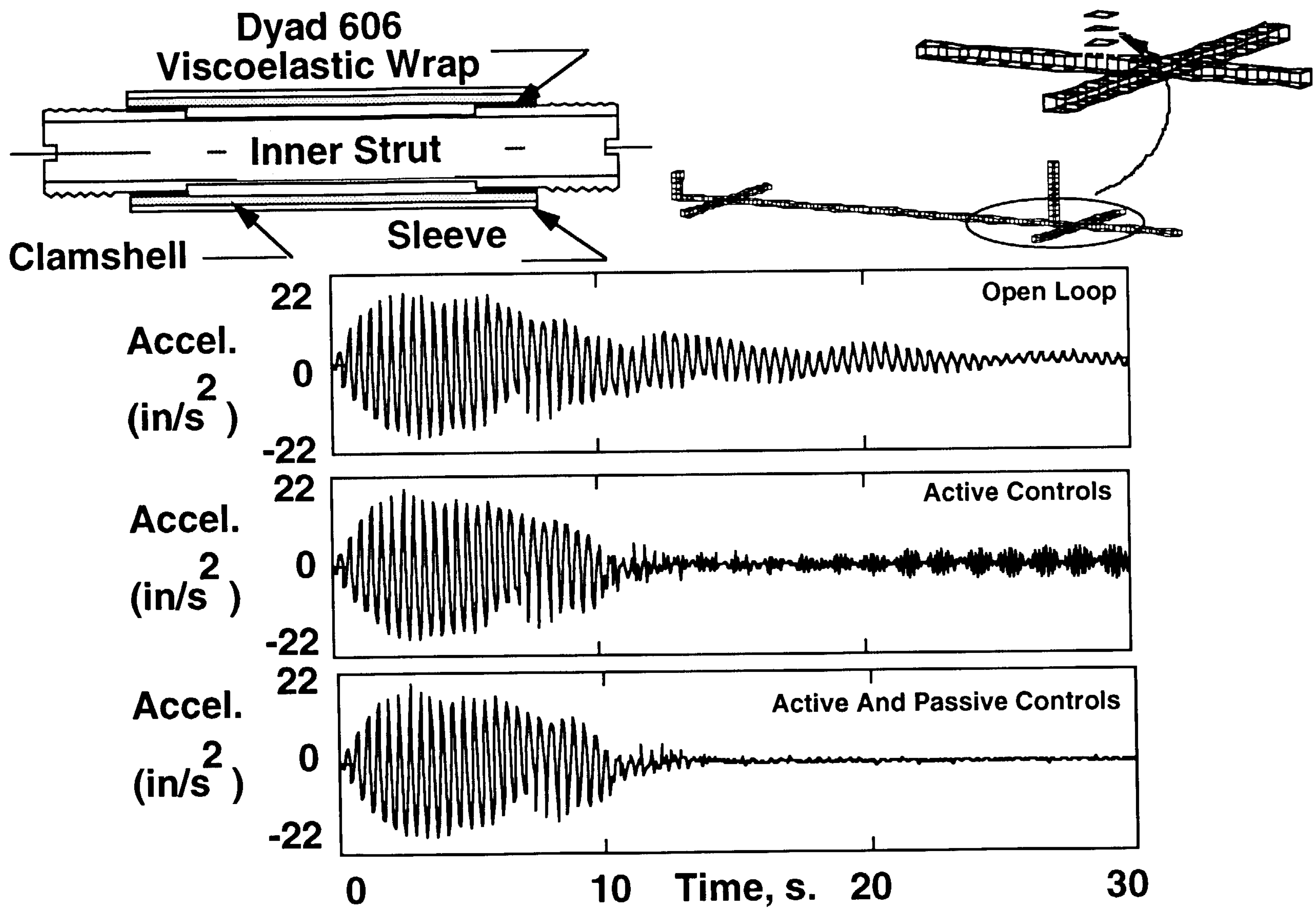


Figure 54 (b).

SECOND-ORDER OBSERVER BASED CONTROL

W. Keith Belvin

RTOP 590-14-61

Objective: Feedback control systems often require an estimation of states that cannot be measured directly from the system under control. This study was aimed at improving the state estimation of structural systems by reducing the sensitivity to model error and unmodeled dynamics.

Approach: A second-order differential equation form was used to develop a model for estimation of structural states. This differs form the more common first-order state estimator such at the Kalman Filter. By using collocated sensors and actuators, the new estimator does not require spatial filtering which typically occurs with the first-order estimator.

Accomplishment: To validate the performance of the new observer, tests were performed on a structural testbed designed to study control of flexible spacecraft. The experiments consist of 10 seconds of excitation from on-board thrusters, 2.5 seconds of free decay, and then at 12.5 seconds closed-loop control is initiated. The attached figure shows the experimental response of the structure when using the first-order and second-order observer. The data obtained with the controller that used the first-order estimator shows and instability which required the actuators to be disabled. This instability is most likely due to error in the estimator design model. The second-order estimator used the same design model and was implemented with the same gains, yet, a stable closed-loop response was observed. The equations of motion for the second-order observer do not require spatial filtering. Thus, sensitivity to model error is reduced.

Significance: The second-order observer proved to be superior for estimating structural states when model error is present. This type of observer improves flexible body spacecraft control by permitting model based design of the optimal control gains while not sacrificing stability margins due to error in the design model.

Future Plans: Further studies are planned by extending this work to structural systems with embedded actuators by using collocated strain measurements to derive a second-order observer model.

Figure 55 (a).

SECOND-ORDER OBSERVER BASED CONTROL

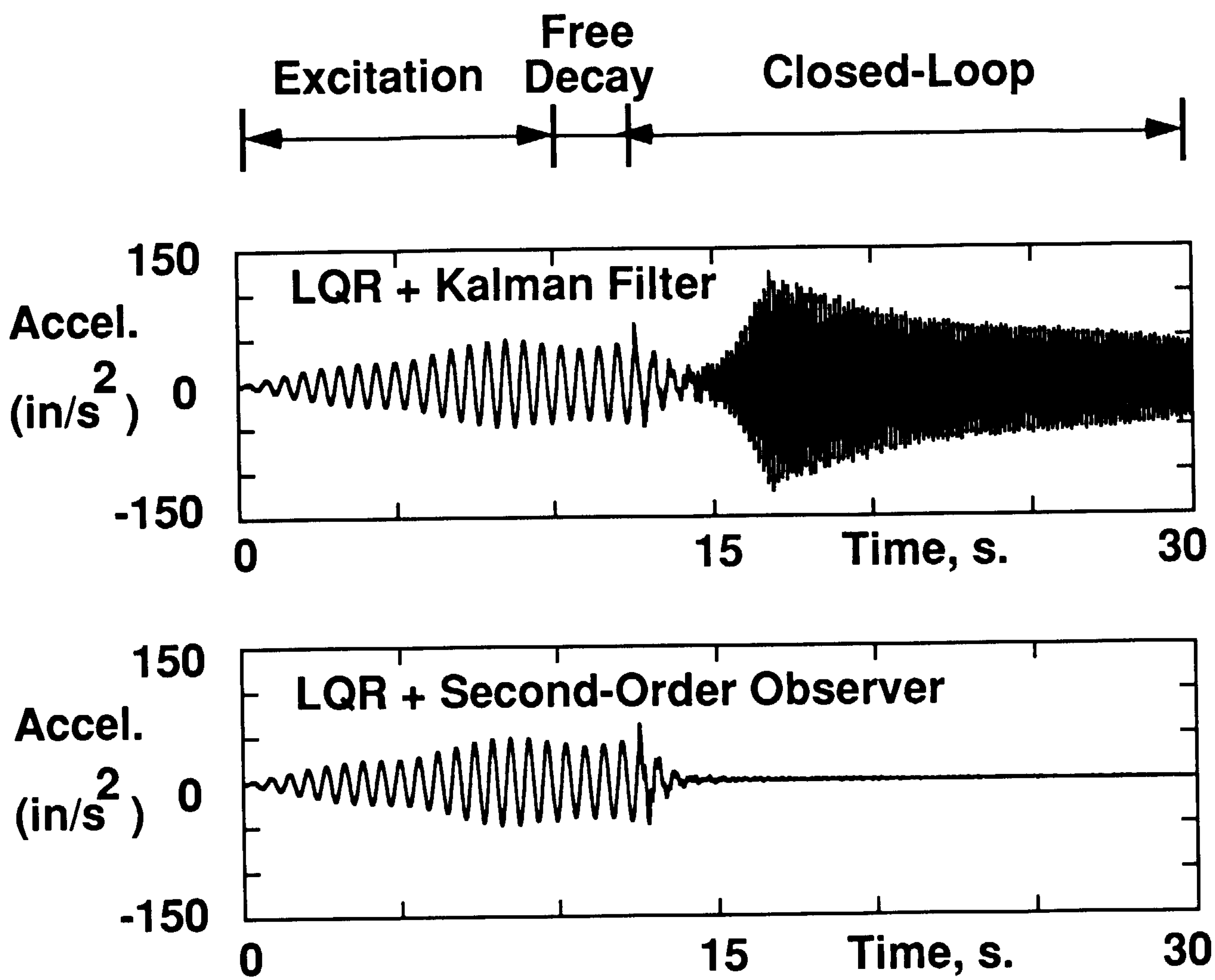


Figure 55 (b).

MAGNETOSTRICTIVE STRUT CONCEPT DEVELOPED UNDER PHASE 1 SBIR

C. Garnett Horner

RTOP 585-03-11

Objective: Develop an advanced strut concept using magnetostrictive actuation

Approach: To evaluate the most promising magnetostrictive materials for space structures applications and to fabricate a strut from the most promising material. The chosen magnetostrictive material will be tested and evaluated. A strut fabricated using the magnetostrictive material will be tested to confirm the analysis prediction.

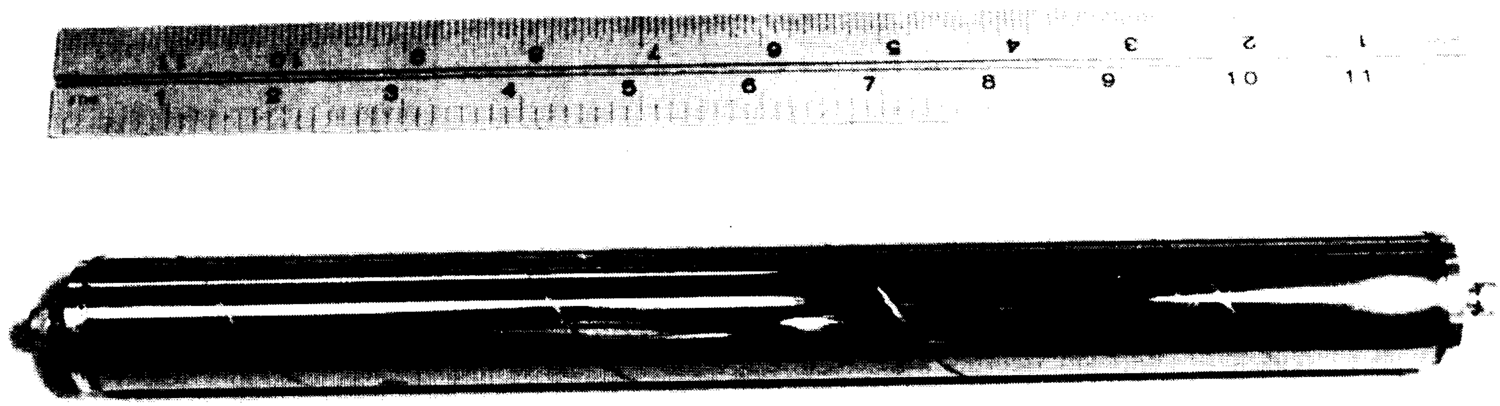
Accomplishments: The two most promising magnetostrictive materials were evaluated. The two materials, Terfenol-D and Metglas, have a high modulus and strength which would make them suitable for structural load bearing elements. Based upon the information about ease of fabrication, power conversion, and strain, Metglas was chosen as the material for fabricating a strut. A strut consisting of 10 layers of Metglas foil was fabricated. The strut was 10 inches long, 1 inch diameter, .015 inch wall thickness and weighs .2 pounds. The measured magnetostriction (strain) is 53 ppm. and the predicted clamped force is 25 pounds. The strain in the strut was produced using an axially aligned magnetic field from a coil surrounding the strut.

Significance: The control of truss structures for space requires the action of a force in the load path of the truss. The Metglas strut accomplishes this task and should function as a "dumb" strut with adequate load carrying capability. The conversion of magnetic energy into strain energy is very efficient (90%) and is accomplished using a low voltage (~2 volts) and low power (~.75 watts) source.

Future Plans: The current plans are not to continue this work in the SBIR program. Additional work needs to be due to determine the failure load of fabricated Metglas struts and to incorporate the magnetic coil into the strut fabrication.

Figure 56 (a).

MAGNETOSTRICTIVE STRUT CONCEPT DEVELOPED UNDER PHASE 1 SBIR



- Developed by SatCon Technology Corp.
- Magnetic field driven
- Low power, low voltage (compared to piezoelectric devices)
- Up to 90% energy conversion efficiency
- High strength material (fly wheel applications)

Figure 56 (b).

CEM PHASE-1 VIBRATION SUPPRESSION USING PIEZOELECTRIC ACTUATORS

D.W. Sparks, Jr.
Spacecraft Controls Branch

C.C. Won, C.A. Sandridge and J.L. Sulla
Lockheed Engineering and Science Company

RTOP 585-03-11

Objective: To demonstrate the feasibility of using piezoelectric actuators to excite and to suppress vibrational motions of the CSI Evolutionary Model (CEM) Phase-1 Testbed. The goal is to eventually replace the current cold gas thrusters with active struts, such as piezoelectric actuators, to perform all flexible body control on the CEM.

Approach: Eight commercially available piezoelectric actuators were purchased for this work. These actuators were selected based upon their expansion and load carrying capabilities, as well as having the proper dimensions in order to fit inside a single truss bay of the CEM. Special adapters were designed and fabricated so the actuators could be placed in the CEM, taking the place of normal strut members in selected locations. An integer-linear-programming algorithm was used to determine the optimal locations of these eight actuators in the CEM. The optimization objective was to maximize the minimum sum of the modal strain energy in selected locations for ten target flexible modes. These ten target modes were chosen from a larger set of previously identified flexible modes due to their modal strain energy levels; those with the highest levels of modal strain energy were deemed to be the most controllable with the piezoelectric actuators. Several other sets of locations for these eight actuators were selected manually, using engineering judgment. Open loop tests were performed on these manually chosen sets of locations, along with the optimal set, to measure the effectiveness of the optimal placement.

With the eight piezoelectric actuators placed in their optimal locations, and using the existing eight servo accelerometers as sensors, an 160-state linear model of the CEM was identified using OKID. Based upon this identified model, a LQG digital control law was designed and implemented on the CEM to suppress vibrational motion.

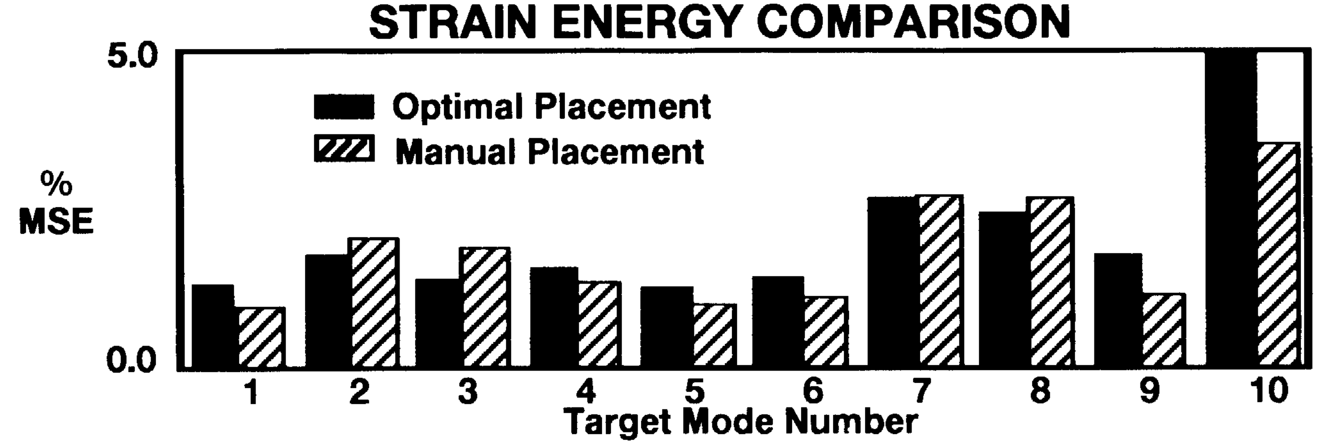
Accomplishments: Vibration suppression on the CEM Phase-1 using piezoelectric actuators has been experimentally demonstrated. The effectiveness of the optimal placement algorithm, as applied the CEM, has also been shown. The top figure is a bar chart comparing the percent of modal strain energy in each of the ten target modes as seen by the optimally placed struts and manually placed struts, respectively. The bottom figure shows open and closed loop test results measured by the same accelerometer. The piezoelectric actuators increased the damping in target mode 10 by almost a factor of 13.

Significance: The results show that it is feasible to use piezoelectric actuators for vibration suppression on large space structure models such as the CEM. By properly selecting the numbers and locations of these actuators, it may be possible to eliminate (or at least reduce) the reliance on gas propellant based actuators for flexible motion control.

Future Plans: These include the placement of more piezoelectric actuators on the CEM, and using other sensors for control feedback, such as strain gages, piezo film strain rate sensors and load cells in near collocated configurations with the actuators. The development and implementation of decentralized controllers, e.g., using the piezoelectric actuators and their near collocated sensors in local feedback loops, will be investigated on the CEM.

Figure 57 (a).

CEM PHASE-1 VIBRATION SUPPRESSION USING PIEZOELECTRIC ACTUATORS



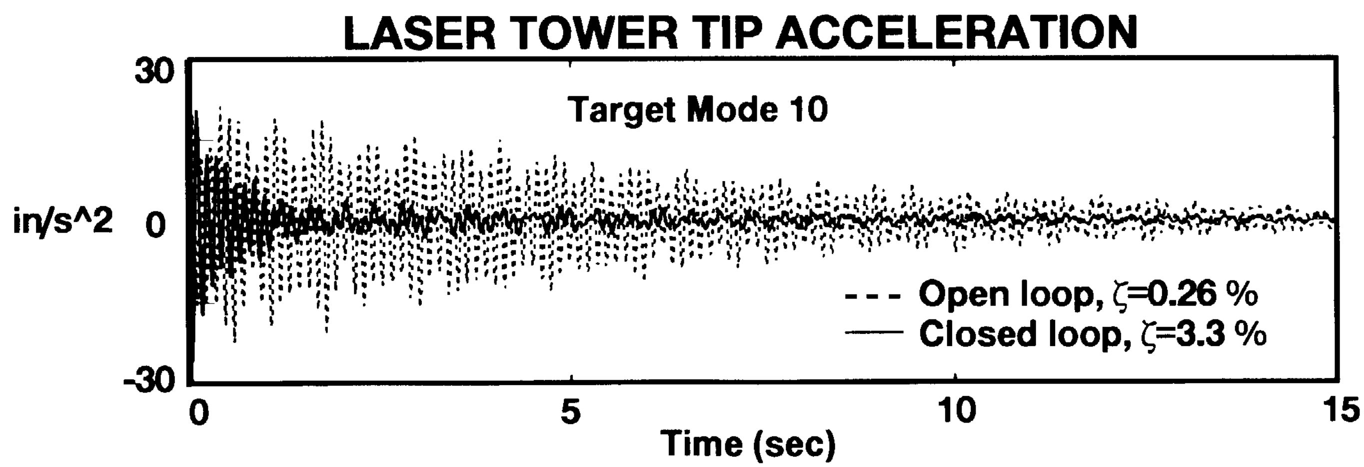


Figure 57 (b).

PERFORMANCE IMPROVEMENTS FOR THE CSI CEM REAL-TIME CONTROL SYSTEM

Kenny Elliott
Spacecraft Dynamics Branch

Roberto Ugoletti and Jeff Sulla
Lockheed Engineering and Science Company

RTOP 590-14-61

Objective: The CSI Evolutionary Model (CEM) has been developed to validate advanced control technology for spacecraft applications. A primary part of this testbed is a real-time digital control system. Originally, the control system supported a controller size of 16 states operating at a frame rate of 125 Hz. The goal of this work is to increase the speed and computational throughput of the control system with the objective of supporting controls research that uses controllers sized at up to 50 states and operates at frame rates up to 500 Hz.

Approach: An analysis of the system's performance was performed. This analysis consisted of analyzing clock and frame overruns to determine when and how they occurred. Also, timing studies were performed on hardware and software components. A clock overrun occurs when the system takes longer time then specified to complete one frame, and a frame overrun occurs when a frame has been skip. By determining detailed timing relationships and the reasons for clock and frame overruns, methods for improving the performance of the system could be developed. These methods involved: cost effective hardware changes, getting control over the CPU, reducing background activity, defeating virtual memory, reducing input and output (I/O) bottlenecks, changing the operating system, and optimizing the controller software algorithm.

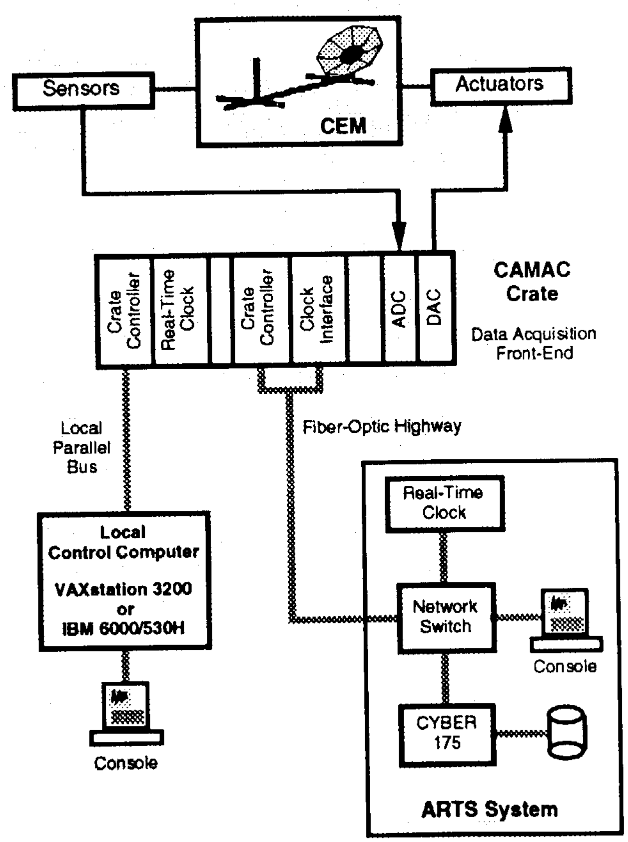
Accomplishments: One measure of a control system's performance is the speed (frame rate) that the system can run a certain size (computation load) controller without incurring clock or frame overruns. The evolution of this system's performance, as delineated by the evolution of the control CPU, is shown in the attached figure. The lower curve gives the performance of the original system that used a CYBER 175 as the CPU. This system was part of Langley's Advanced Real-Time Simulation (ARTS) system. The system was primarily handicapped by its I/O speed. The middle curve gives the performance of the system using a VAX 3200 workstation as the CPU. Originally, the VAX system's performance was equivalent to the ARTS system; however, by using the above approach, the VAX system's performance was improved by a factor of 3 to 4. The upper curve gives the performance of the current system which is based on an IBM-RISC CPU. The performance improvement for the IBM system is primarily due to the increase in CPU performance of the RISC CPU architecture.

Significance: The control system is the instrument for executing controls research on the CSI CEM testbed. It is also an integral part of the control synthesis. An approach has been used to effectively evolve the performance the control system in order to support increasing requirements of the controls research.

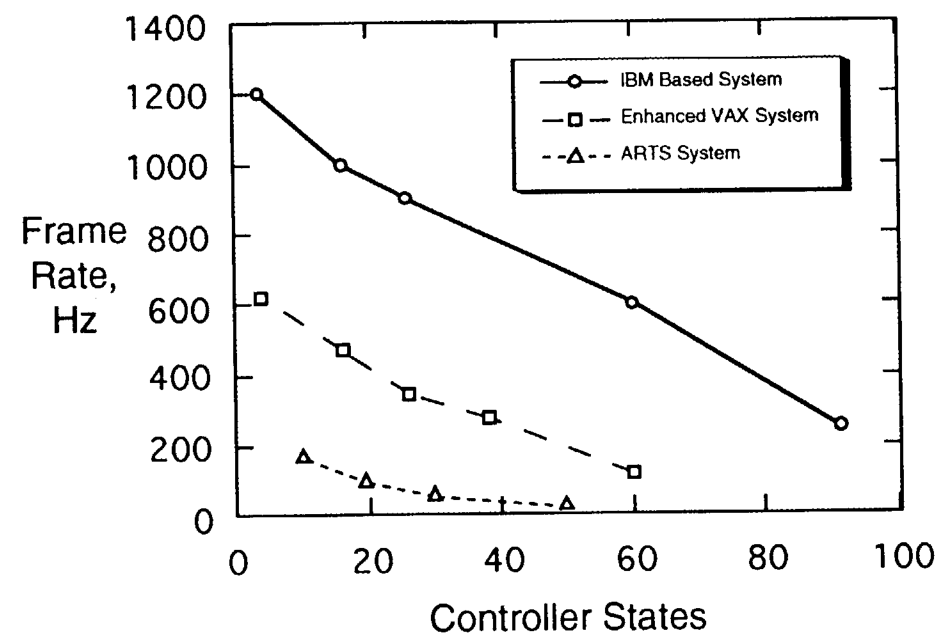
Future Plans: Plans are to continue critical assessments of this system to determine the means of improving performance as required by the controls research. In addition, the capabilities of this system are being expanded to meet control research requirements, such as, handling network communications during control and studying different controller topologies (centralized, decentralized, and hierarchical).

Figure 58 (a).

PERFORMANCE IMPROVEMENTS FOR THE CSI CEM REAL-TIME CONTROL SYSTEM



Control System



Control System Performance

Figure 58 (b).

MACE SYSTEM IDENTIFICATION STUDIES

Lucas G. Horta and David W. Miller (MIT)

RTOP 590-14-61

Objective: MACE (Middeck Active Control Experiment) is a flexible multi-body dynamics and controls flight experiment to be conducted in the shirt sleeve middeck environment of the Shuttle. The overall objectives of MACE are to validate the CSI (Control-Structure Interaction) modeling tools associated with flexible multi-body dynamics coupled with active structural control and to examine issues associated with non-zero gravity ground testing. The approach is to design a small flexible testbed (2 Hz) and perform a set of experiments which captures the essential physics of precision spacecraft structures. The testbed, sketched in the following figure, consists of a multi-segmented lexan beam, a torque wheel for attitude control, and an active member for active vibration damping. Attached to both ends are two axes gimbals which point rigid payloads. Three axes rate gyros are mounted on the torque wheel and on the outer stage of each gimbal. Two axes accelerometers are attached to the intermediate nodes as well as a series of strain gages cemented to the segmented lexan beam. The MACE program is sponsored by NASA Langley Research Center under the CSI program office and is the responsibility of MIT SERC (Space Engineering Research Center). The objective of the work at LaRC is to apply the recently developed system identification algorithms (ERA/DC and OKID) and to produce a test verified model from ground test data and on-orbit data.

Approach: The approach at LaRC in conjunction with MIT is to perform ground system identification experiments on the testbed located at MIT and to evaluate the gravity effects. An attempt was made to minimize the gravity effects by suspending the testbed on a 15 foot pendulum (isolation freq = 0.2 Hz) coupled with an advanced active pneumatic vertical isolator (0.2 Hz). The plan is to excite the structure, using the available actuators, to identify a model of the structure. Both a tuned distributed parameter model and a verified measurement model are products from this effort.

Accomplishments: The testbed development is being accomplished in three stages (development, engineering, and flight). The development model includes early versions of the gimbals, torque wheel, and segmented beam. The engineering model when finalized will be flight similar. Several test runs have been completed on the engineering model which has the development torque wheel and engineering model gimbals. These results indicate that there is a gravity influence from the suspension system because the testbed has significantly different frequency characteristics in the two orthogonal lateral directions. A comparison of test data with the distributed parameter model is shown in the figure. Because the torque wheels are mounted at a location of zero slope for the first flexible mode, this mode is not excited well.

Significance: The purpose of an accurate model is to aid in the design of the active structural control system which includes sensors, actuators, and digital control computer. The system identification task plays a critical role in model validation and verification. Future adaptive control algorithms are dependent on the development of recursive real time identification techniques. The results of this effort provide the needed next step for space qualification.

Future Plans: Additional tests are planned when the engineering model is available. Participation on an interactive basis during the flight test scheduled for mid 1994 is planned.

Figure 59 (a).

MACE SYSTEM IDENTIFICATION STUDIES

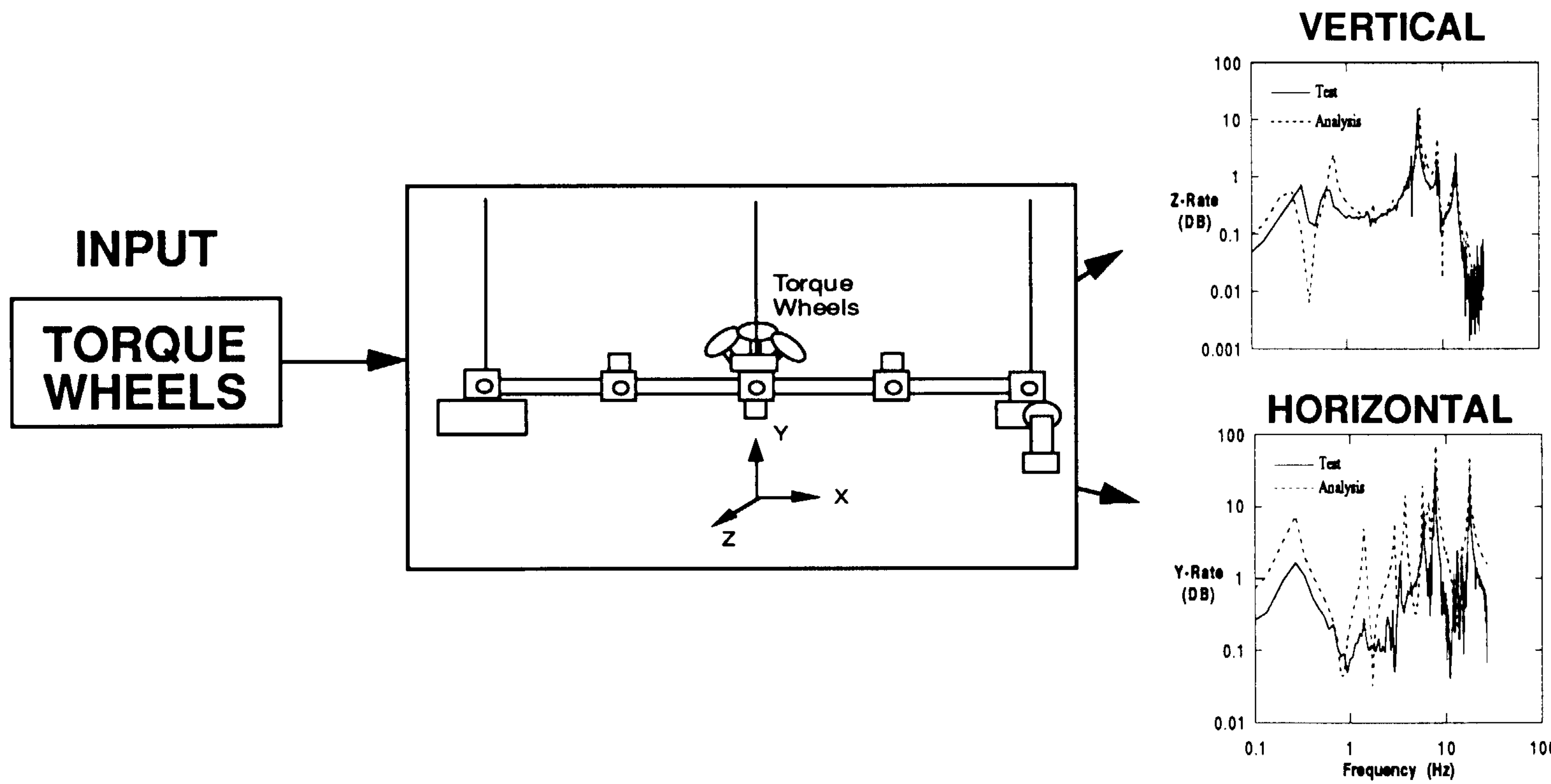


Figure 59 (b).

REAL-TIME SIMULATION EVALUATION OF RMS ACTIVE DAMPING AUGMENTATION

Martha E. Demeo (ViGYAN), Michael A. Scott (SCB), and Michael G. Gilbert

RTOP 590-14-61

Objective: Active Damping Augmentation (ADA) is the application of Controls-Structures Integration (CSI) Technology to benefit the on-orbit performance of the Space Shuttle Remote Manipulator System (RMS). The goal is to reduce the vibration decay time of the RMS following normal payload maneuvers and operations. Simulation of ADA was conducted in the real-time man-in-the-loop Shuttle Engineering Simulator (SES) at NASA's Johnson Space Center (JSC) with the objective of obtaining a qualitative definition of RMS operational performance improvement by astronaut operators and obtaining supporting quantitative performance data.

Approach: Vibratory motions are sensed using a simulated three-axis accelerometer mounted at the end of the lower boom of the RMS. The sensed motions are feedback to the ADA control law, implemented in the Shuttle General Purpose Computer (GPC), which generates commands to the RMS joint servo mechanisms to reduce the unwanted oscillations. The ADA control law was implemented following termination of operator commands so as to maintain the current RMS operational "feel". Successful synthesis and implementation of baseline point design compensators lead to development of a single ADA control law designed to work over a range of arm configurations.

Accomplishments: Active damping of the RMS with an attached 4000 lb. payload was successfully demonstrated. Six astronaut operators (Thagard, Brown, Sherlock, Godwin, Reightler and Thuot) examined the performance of an ADA control law following single joint and six joint coordinated translational and rotational maneuvers. ADA disturbance rejection of Shuttle thruster firings was also evaluated. Comments on ADA's potential operational performance benefit ranged from " limited" to "a big improvement".

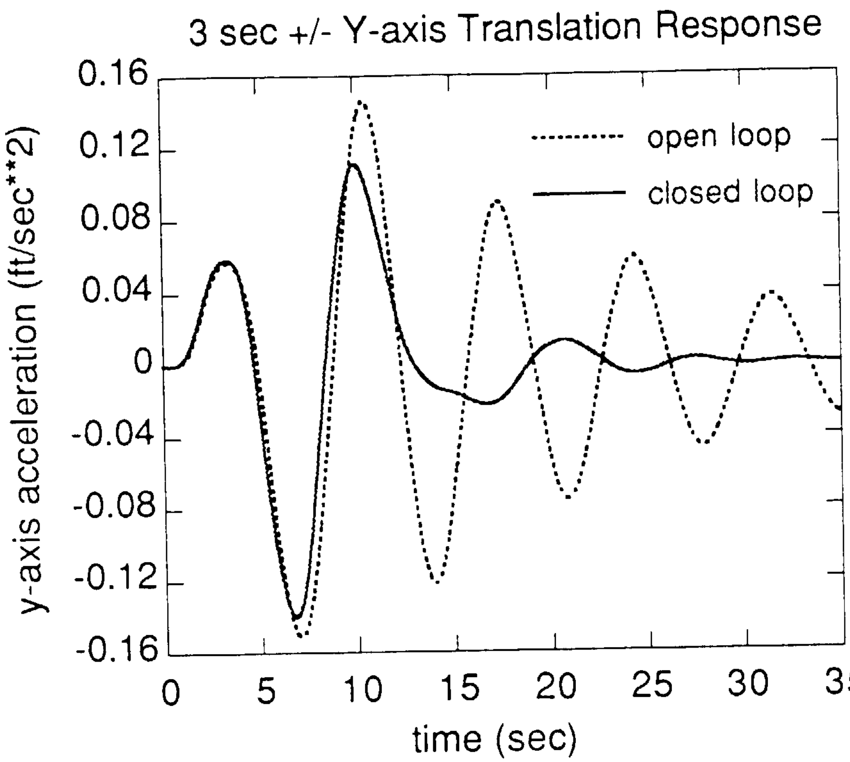
Significance: The time required for oscillations to disappear on the current RMS can impact timelines and reduce operational flexibility when handling payloads. The application of ADA reduces the amount of wait time between RMS maneuvers and thus increases the operational efficiency of the RMS.

Future Plans: Based on the unanimous recommendation of the astronaut operators, future plans are to investigate ADA benefit to heavy payloads where oscillations are a bigger problem (e.g. space station assembly operations).

Figure 60 (a).

REAL-TIME SIMULATION EVALUATION OF RMS ACTIVE DAMPING AUGMENTATION

Astronaut Nancy Sherlock in SES



The RMS "definitely damps out faster" and the "final stop point (is) more predictable" (Ken Reightler)

"You can tell a difference between ADA on/off but not sure how big an effect this will have operationally" (Norm Thagard)

"It is obvious that the arm performs better with ADA" (Pierre Thuot)

Recommend evaluating ADA with heavy payloads. (All)

Figure 60 (b).

UPPER ATMOSPHERE RESEARCH SATELLITE (UARS) DISTURBANCE EXPERIMENT

Stanley E. Woodard and William L. Grantham (CSI Office)
RTOP 590-14-61

Research Objective: The primary goals of this experiment were to ascertain the pointing jitter contribution of each individual gimballed instrument and to provide on-orbit experimental data to compare with pre-launch response predictions and those derived from a new Controls-Structures Interaction (CSI) multi-body dynamic simulation. An ancillary objective of the experiment was to provide system responses suitable for identifying damping and frequency of modes excited due to prescribed inputs.

Approach: The controlled disturbance experiment on UARS was scheduled to take place during the last 4 hours of the routine spacecraft yaw-around (180°) day. To successfully isolate the effects of different disturbances, the normal continuous scanning operations of two instruments were altered. The Microwave Limb Sounder (MLS) Team at JPL sent commands, requested by Langley, to their instrument regulating the scan profiles of its 1.6 meter antenna and switching mirror. The commands consisted of on/off sequences for its gimballed antenna and switching mirror. The High Resolution Doppler Imager (HRDI) Team at the University of Michigan also altered their normal sequence of operations scheduled for the yaw-around day. The HRDI Team interrupted its calibration at the beginning of the experiment and began its normal scanning sequence such that it served as another isolated disturbance source. The scan schedules of the MLS and HRDI instruments were interwoven with other routine disturbance sources making it possible to have each instrument's disturbance both isolated as shown in the attached figure and in combination with other disturbances. The gray scale code shows disturbance on-times for the three orbit period. Also shown is the time history of roll rate gyro data during solar array thermal snap and solar array vibration at the fundamental frequency of about 0.23 Hz.

Accomplishments: On May 1, 1992, the NASA Langley requested disturbance sequences were successfully executed on-board the UARS spacecraft. The experiment provided (13) isolated disturbance events, (24) multiple disturbance events, (3) sunrise solar array thermal snaps, (2) sunset solar array thermal snaps, and 33 minutes with all major disturbances removed. Every gimbaled instrument on-board the satellite was moved both individually and with other instruments during the experiment. One of the first observations using the May 1 data was the unexpected disturbance from the solar array drive mechanism which causes near continuous excitation of the 0.23--0.26 Hz. solar array elastic mode. Because of that, additional data has been obtained after the May 1 experiment for the "No Disturbance" case taken when the solar array motor was off. General Electric (GE) is in the process of including the solar array drive as a disturbance source in their model.

Significance: A major output of the CSI Program is the improved prediction accuracy of spacecraft pointing jitter so that adequate (but not excessive) design margins can be used to assure mission success. In cases such as UARS and EOS-AM, jitter can result from flexible appendages (solar arrays, booms, etc.) being excited by one or more disturbance sources. UARS has five gimballed instruments and a gimballed solar array which contribute to the spacecraft overall dynamics. Prior to launch the method used by GE to predict UARS jitter consists of treating each disturbance separately and then summing the responses using root-sum-squared to give a worst case overall jitter. The CSI multi-body dynamic simulation approach includes all disturbances operating simultaneously which allows for the mutual interaction that the instruments have on each other. The UARS Disturbance Experiment has provided disturbance cases suitable for evaluating both methods of analysis.

Future: Analysis has begun to show how the various disturbances contribute to pointing jitter. The jitter response will be computed from both the pre-launched analytic model developed by GE and a multi-body dynamic model under development and compared.

Figure 61 (a).

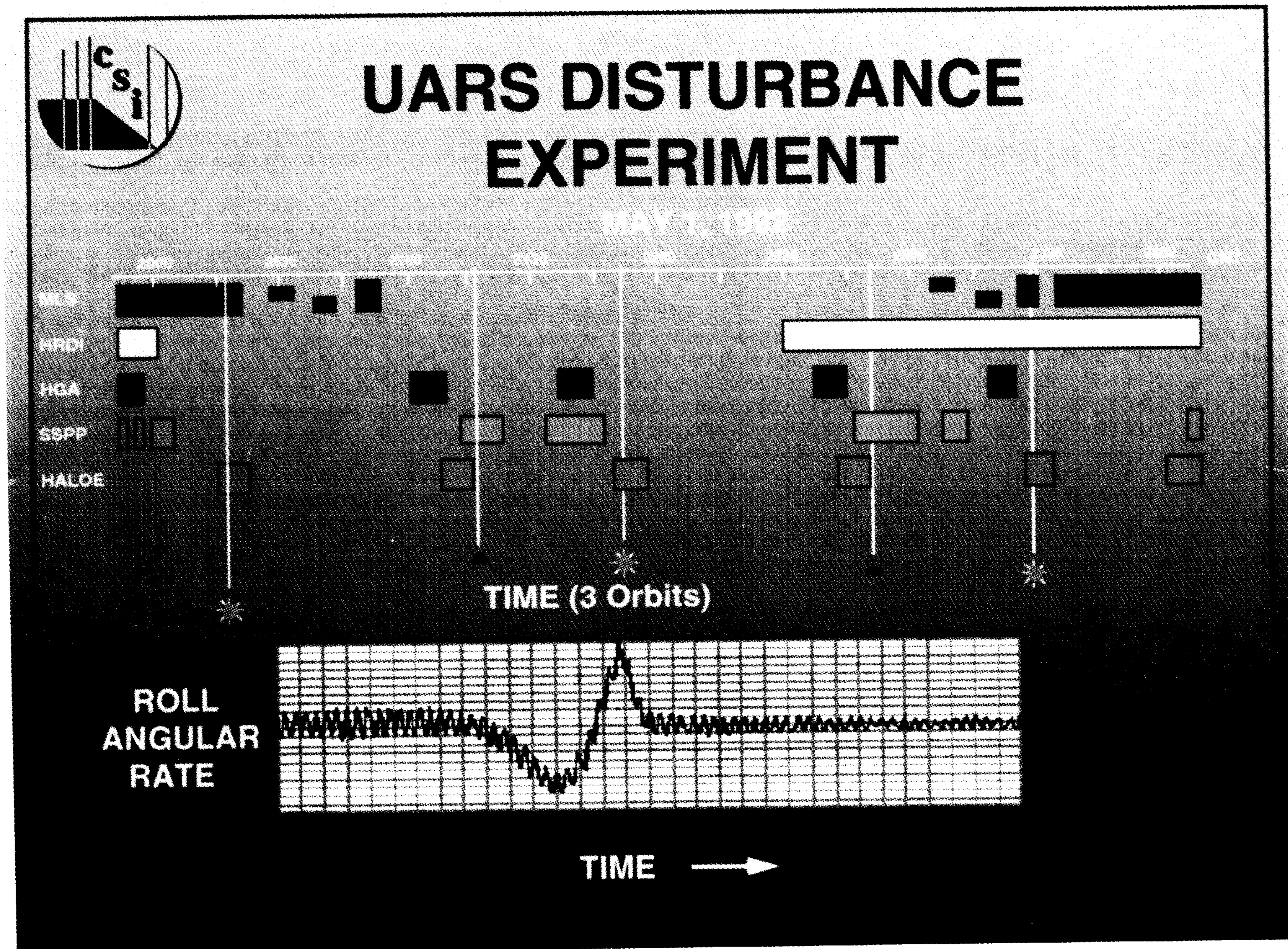


Figure 61 (b).

ORIGINAL PAGE IS
OF POOR QUALITY

TEST/ANALYSIS CORRELATION OF DSMT HMB-2R SPACE STATION MODEL COMPLETED

Mehzad Javeed (LESC), Harold H. Edighoffer (AS&M), Paul E. McGowan
RTOP 590-14

Research Objective : To validate procedures for updating system level Finite Element Models (FEM) based on inclusion of test verified component models.

Approach : The trend toward increasing size and complexity of space structures will reduce the feasibility of verifying the full-system structural models through ground test methods (e.g. Space Station Freedom). For this class of structures more emphasis is placed on verifying models of segments of the full-system structure at the component/subassembly level. The full structural model of the system is synthesized from assembly of the component/subassembly level verified models. One of the objectives of the Dynamic Scale Model Technology (DSMT) program is to assess the feasibility of this approach. A hybrid scale model of the (earlier) erectable space station design, representing the Mission Build-2 configuration (HMB-2), was selected as the focus structure. This model was divided into 26 components, consisting of 10 bays of truss, rotary alpha and beta joints, various pallets, and both "rigid" and "flexible" versions of solar arrays and radiators. Static and dynamic tests of each component were performed to determine their structural characteristics. The individual components were tested with boundary conditions that approximate as nearly as possible those which the component has as part of the integrated system. The FEM of each component was modified based on test results. A design sensitivity approach was utilized to update component FEM. The updated models were then used to form the system model. Results computed using the newly formed system model were then compared with results calculated using the pretest system model to establish the effects of updated component models.

Accomplishment Description : For this work the dynamically simpler version of the HMB-2 model with "rigid" appendages (designated HMB-2R), was studied. Static and dynamic tests of the components have been completed. All component FEM have been updated to agree with test results. The full-system test and data analysis of the HMB-2R model have also been completed. The correlation between the full-system test and analysis models is much improved due to inclusion of the test verified FEM of the components. The FEM of the system was further improved by refining the FEM of the appendage-to-truss interfaces. As indicated in the figure, results computed using the final updated system FEM were in good agreement with test results, the maximum error in frequency being less than 5 percent. The frequency range of analysis for HMB-2R model was from 0 to 25 Hertz.

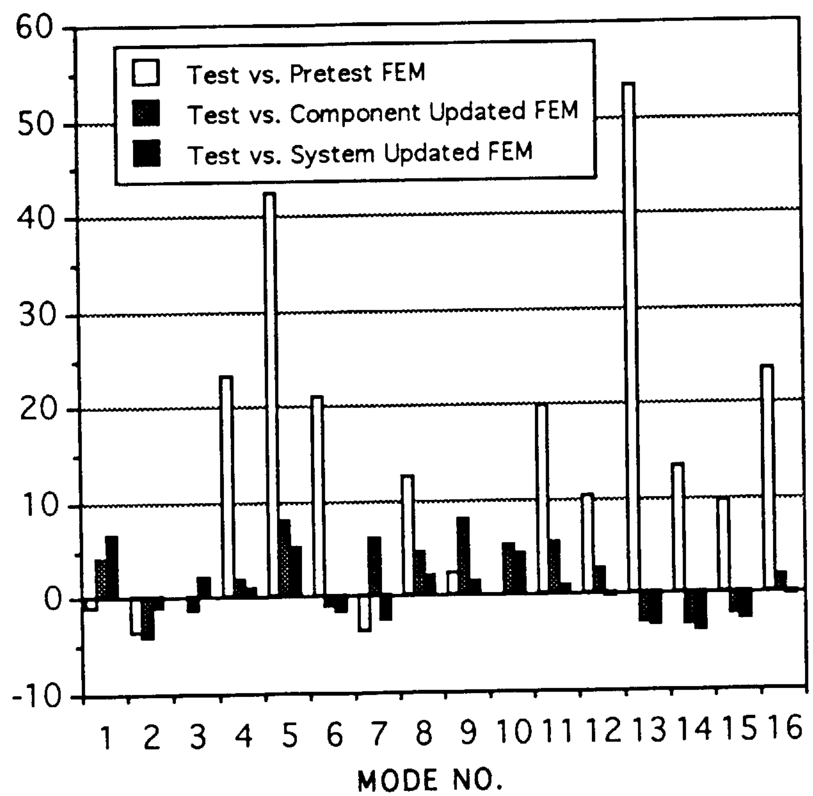
Significance : The quality of the results of this approach is highly dependent on verification of the interface characteristics of the components/subassemblies. The improvement that was achieved as the result of the full-system level test and FEM correlation indicates that access to test data from the integrated full-system model is very important. The knowledge gained from the test/analysis verification process in this program will be applicable to large space structure programs, such as the space station program.

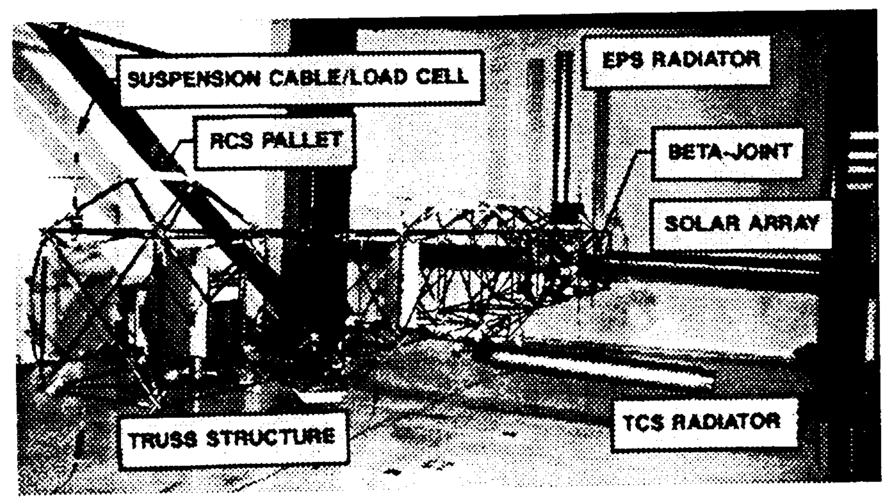
Future Plans : The correlation analysis between test and FEM of the HMB-2 model with flexible appendages (HMB-2F) will be conducted. The results of HMB-2R and HMB-2F test/analysis correlations will be documented.

Figure 62 (a).

TEST/ANALYSIS CORRELATION OF DSMT HMB-2R SPACE STATION MODEL COMPLETED

FREQUENCY COMPARISON





HMB-2R Model

Figure 62 (b).

EIGHT-BAY DAMAGE LOCATION TESTS VERIFY NEW EIGENSTRUCTURE ASSIGNMENT METHOD

Thomas A. L. Kashangaki and Tae W. Lim (LESC)

RTOP 590-14-31

Research Objective: To develop and validate a method by which measured modal data can be used to detect and locate damage in flexible space structures.

Approach: Large space structures, such as Space Station Freedom, are apt to suffer structural damage during their service life due to such events as docking and impact from foreign objects, and from adverse effects associated with long-term exposure to a space environment. From the standpoint of both safety and performance, it is desirable to monitor the structural integrity of such structures to detect the occurrence of any damage and to identify its location and extent. A detailed review of existing techniques and current research activities in this area led to the identification of several possible approaches for a new damage location method. The new method which has been developed is based on an innovative application of the eigenstructure assignment method used in controls work. Development of the method was pursued concurrently with a comprehensive test program using an eight-bay section of a dynamically scaled model of an erectable truss structure. Modes, frequencies, and damping for 16 damage cases were obtained for the truss. Damage cases included single members removed, multiple members removed, and partial damage to a single member. Three accelerometers at each node (for a total of 96) provided complete mode shape definition for the structure. Detailed parametric studies were conducted to evaluate data accuracy requirements for damage detection.

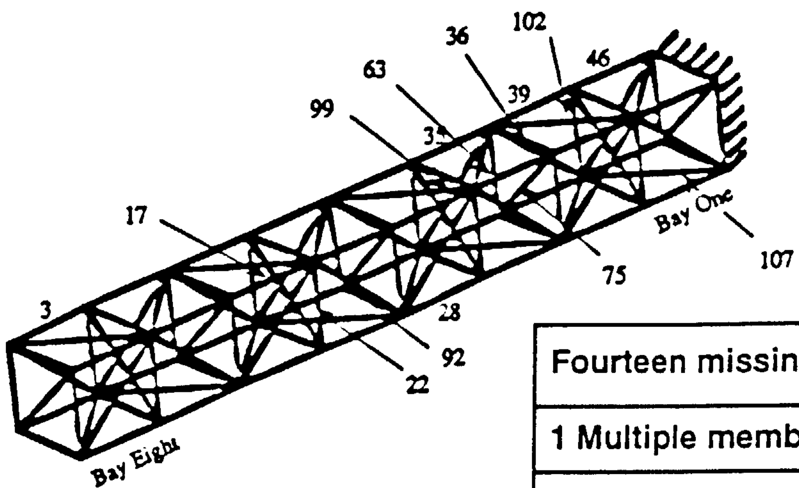
Accomplishment Description: The new damage detection and location method has been validated using the modes and frequencies obtained from ground vibration tests conducted on the eight-bay truss cantilevered from a rigid backstop.The sketch indicates the struts that were involved in the 16 damage cases which were studied. Pre-test strain energy and sensitivity analyses were used to indicate the most likely damage sites. The modes and frequencies produced by assuming damage to each of the suspect members were projected onto the measured modes of the damaged structure and the distance or angle between the two sets of vectors was used to indicate the location of damage. Once the location of the damage was established, the magnitude of the damage could easily be calculated. The table summarizes the results of the damage location studies. In general, damage was detectable, but only to members which were highly strained and only if the damage (e.g., reduction in stiffness) was sufficiently large. The results also suggest that damage detection will be difficult if there is only limited instrumentation on the structure.

Significance: The damage location method developed is robust and is capable of filtering inconsistencies out of the measured data, as well as detecting damage associated with both loss of stiffness and loss of mass. These capabilities constitute a significant advancement of the state-of-the-art in damage location. In addition, the large quantity of high-quality test data which was obtained constitutes a unique database for damage detection work and is currently being used by several other researchers to validate system identification and damage location methods. It is expected that this data will serve the research community for many years to come.

Future Plans: Future enhancements to the method will include the use of limited numbers of sensors and more computationally efficient convergence algorithms. In addition, the method will be evaluated using data from more complex structures.

Figure 63 (a).

EIGHT BAY DAMAGE LOCATION TESTS VERIFY NEW EIGENSTRUCTURE ASSIGNMENT METHOD



	Detected Analytically	Detected Exp.
Fourteen missing member damage cases	14	9
1 Multiple member damage case	No	No
1 Partial damage case	?	Yes

- Damage to highly strained members (near root) is detectable
- Damage detection is difficult with limited instrumentation

Figure 63 (b).

SPACE STATION FREEDOM PRE-INTEGRATED TRUSS SCALE MODEL DESIGN STUDY INITIATED

Victor M. Cooley and Raymond G. Kvaternik

RTOP 590-14-31

Research Objective: To develop and validate ground test and analysis methods based on the use of scale models for predicting and verifying the on-orbit dynamic characteristics of large, flexible, spacecraft structures.

Approach: The structural dynamic characteristics of spacecraft structures have traditionally been verified by ground vibration tests. However, emerging space structures, such as Space Station Freedom (SSF), will be either too large or too flexible to be tested adequately as complete systems on the ground. Verification will be limited to components and subassemblies only, relying on analyses to predict the on-orbit dynamic behavior of fully-integrated structures. There is underway at Langley Research Center a Dynamic Scale Model Technology (DSMT) Program which has the objective of developing the technology for using dynamically scaled models to simulate the on-orbit dynamics of large space structures. SSF was selected as the focus structure for this research. Under the program, several models of increasing structural and dynamic complexity have been designed, built, and tested. A 1/10-scale model of the (earlier) erectable space station design is presently under study. Current plans are to procure a model of the (current) pre-integrated truss space station design for the study of the on-orbit dynamics of the space station and for conducting basic research in spacecraft structural dynamics.

Accomplishment Description: Under contract, Lockheed Missiles & Space Company is conducting preliminary studies for the design and fabrication of a dynamics scale model of the SC-7 (MTC+) configuration of SSF which is depicted in the figure. Initial efforts in the study have been directed at looking at design options and manufacturing tradeoffs for a near-replica model, with provisions for studying early build configurations ranging from SC-2 through SC-7. Options which offer potential for significant cost reductions (e.g., simulate not replicate) are also being considered. The study of scaling and manufacturing issues associated with scale factors ranging from 1/7 to 1/4 have indicated that a scale factor of 1/5 to 1/4 is best for a near-replica model. Prototype model hardware was fabricated to assess manufacturability of typical truss primary structure at the smaller (1/5) scale. These components included the bulkhead frame and the two I-beam struts (a trunion longeron and a mobile transporter (MT) rail) indicated in the figure. From a fabrication point of view, a scale factor of 1/5 was determined to be the smallest factor at which a replica model could be built. However, a 1/4-scale model was shown to be preferable because it would provide an increased capability for replicating mechanisms and complex components.

Significance: Based on the results of the studies conducted to-date, there appear to be no "show stoppers" associated with the design and fabrication of either a 1/4 or 1/5-scale near-replica model of the SC-7 configuration of SSF.

Future Plans: Define the desired functionality and fidelity required of the model. Continue to explore cost reduction options. Initiate design studies of critical components. The type and fidelity of model which will be obtained will depend upon whether or not SSFP chooses to participate in the scale model program.

Figure 64 (a).

SSF PRE-INTEGRATED TRUSS SCALE MODEL PRELIMINARY DESIGN INITIATED

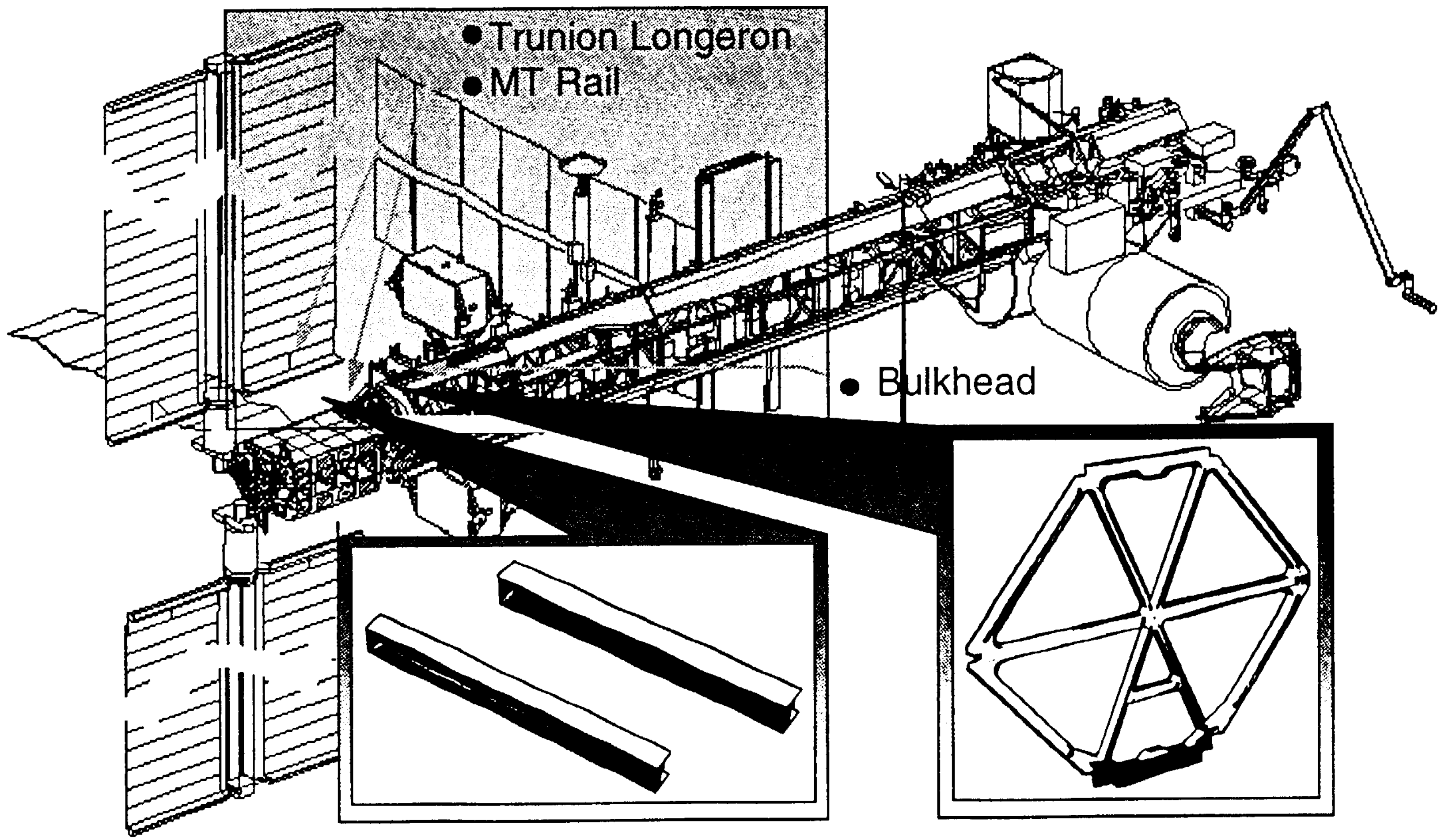


Figure 64 (b).

SUSPENSION DEVICES EVALUATED FOR SPACECRAFT GROUND VIBRATION TESTING

Victor M. Cooley and Anthony A. Giunta

RTOP 590-14

Objective: To evaluate the performance of two suspension systems in simulating near on-orbit boundary conditions so that on-orbit modal properties may be observed and measured during ground vibration testing.

Approach: During ground vibration testing, conventional suspension systems which use hard-mounted steel cables or bungee cords artificially constrain the vibration of large, low-frequency spacecraft relative to their on-orbit vibration properties. Two concepts for devices which would provide for the simulation of on-orbit boundary conditions have been developed and designed. One concept is an all-mechanical, passive design, and the other is a hybrid pneumatic/electromagnetic, active design. Four copies of each design have been built. For both concepts, a structure is suspended (as shown in the figure) by a small number of long cables attached at discrete points. The long cables provide the necessary low stiffness for motions parallel to the ground. The top of each cable is attached to a suspension device which simultaneously supports the weight of the model and provides low stiffness in the vertical direction. Low stiffness constraints at discrete points on the model, while not identical to the unconstrained conditions on-orbit, allow for simulation of on-orbit boundary conditions. The approach for the laboratory evaluation of the two device types is to conduct a softly constrained (suspended) ground vibration test of a low-frequency structure whose unconstrained vibration properties are known. Comparisons of the suspended modal properties to those of the unconstrained body then provide measures of suspension device performance. Baseline unconstrained properties were established by testing the model without the suspension devices and with the model oriented such that its dynamic properties were not sensitive to suspension constraints. Reorienting the model, so the properties were sensitive to suspension constraints, and testing with the suspension systems then provided properties directly comparable to the target baseline properties. The accompanying table compares target frequencies and damping ratios to those measured with both types of suspension devices.

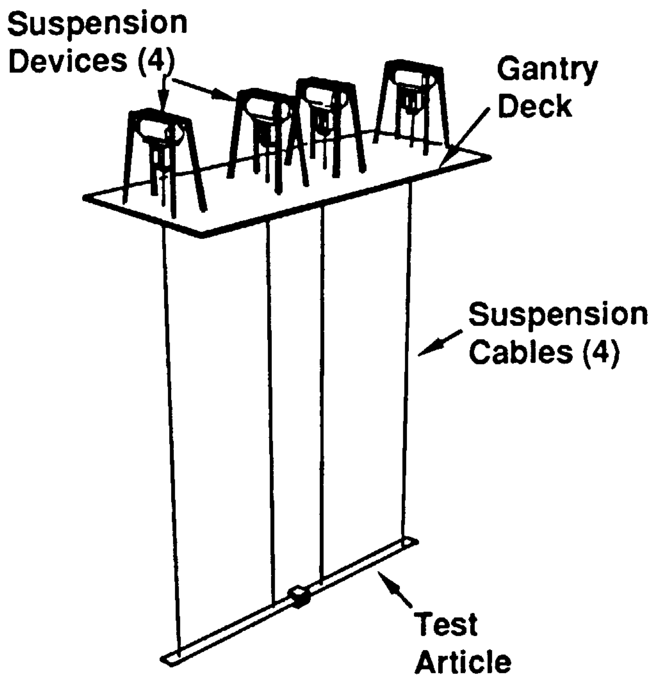
Accomplishment: Initial evaluation of the suspension concept employing both types of devices and using a 26 ft long aluminum beam in a four-cable arrangement as indicated in the figure has been completed. The beam is dynamically similar to the Mission Build 5 configuration of LaRC's one-tenth scale erectable space station model and was designed so that it could be tested with or without the use of the new suspension systems. For this beam, the suspension system resulted in three translational rigid body modes with frequencies ranging from 0.14 to 0.16 Hz, which is substantially lower than the first elastic mode.

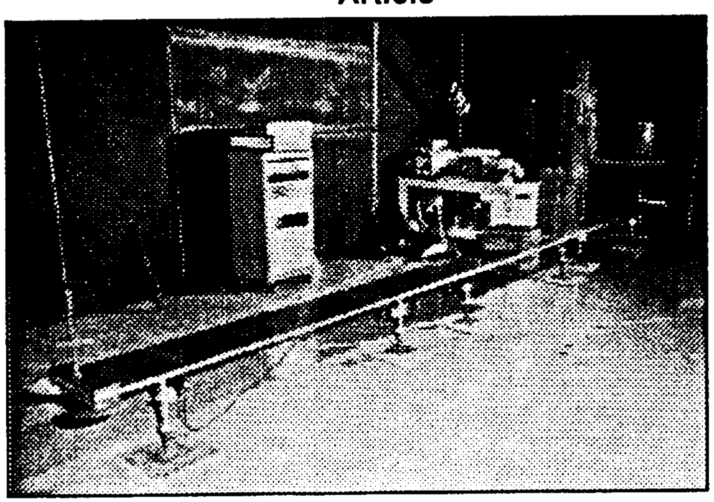
Significance: Both concepts provide substantial improvement over conventional suspension systems, but some differences remain. Both systems result in frequencies which are different from the target frequencies by up to 5.4%. Differences between target and suspended frequencies can be attributed to a combination of mass, stiffness, and/or damping coupling between the test article and the suspension systems. Mass coupling lowers natural frequencies, stiffness coupling raises them, and damping coupling has a near-negligible frequency lowering effect. Since all suspended frequencies are lower than target frequencies, it can be concluded that the effects of mass coupling dominate over those of stiffness coupling.

Future Plans: Preparations are underway to use all eight devices in an eight cable arrangement to support a one-tenth scale model of the earlier erectable space station design.

Figure 65 (a).

SUSPENSION DEVICES EVALUATED FOR SPACECRAFT GROUND VIBRATION TESTING





	Target	ZSRM		P/ESD	
Mode	Freq., Hz.	Freq., Hz.	% Diff.	Freq., Hz.	% Diff.
1	1.11	1.09	-1.8	1.05	-5.4
2	3.97	3.82	-3.8	3.78	-4.8
3	7.03	6.82	-3.0	6.70	-4.7
4	13.66	13.24	-3.1	13.19	-3.4

	Target	ZSRM	P/ESD
Mode	Damping % critical	Damping % critical	Damping % critical
1	0.12	0.35	1.03
2	0.10	0.18	0.35
3	0.08	0.10	0.15
4	0.03	0.11	0.17

Figure 65 (b).

LABORATORY SIMULATIONS DEMONSTRATE FEASIBILITY OF ON-ORBIT MODAL TEST

S.E. Tanner, R.R. Gold (DEI), I.P. Friedman (DEI), and R.H. Tolson (GWU)

RTOP 590-14

Objective: On-orbit modal identification tests are planned for *Space Station Freedom (SSF)*. Through ground tests using realistic models, researchers can study practical issues associated with on-orbit complications, including system identification of a low frequency structure with high modal density, the use of a limited number of sensors at predetermined locations, and the effectiveness of specially-designed randomized pulses from *SSF's* thrusters as excitation forcing functions.

Approach: Ground testing of a generic space station structure was used last year to validate simulations of on-orbit tests of *SSF* planned through the Modal Identification Experiment (MIE). Follow-on tests have been performed this year using the Dynamic Scale Modeling Technology (DSMT) Program's hybrid-scaled model of a previous erectable *SSF* design. When subjected to a standard ground vibration test (GVT), including moving sensors and/or actuators to enhance the system's modal response, this DSMT model, with its flexible appendages, has 54 uniquely identified modes below 5 Hz. (The generic model used last year had 20 modes below 25 Hz.) The current model also includes a set of rigid appendages representing inertial properties only; their high frequency dynamics reduce modal density in the low frequency range of interest. Modal tests were conducted, varying the number of sensors from 13 to 108, using both sets of appendages and multiple shaker inputs. Shaker positions and alignments were determined by *SSF* thruster locations. Burst random excitation, a standard in vibration testing, was compared with scaled versions of an experiment-unique excitation (randomized pulses) planned for the on-orbit tests. Modal identification was performed using the Eigensystem Realization Algorithm (ERA). Results from standard GVT tests were then compared with MIE tests.

Accomplishment: Randomized pulses were shown to be as effective as burst random excitation when the MIE restrictions in exciter locations were maintained. However, a comparison with the GVT highlights the over-all effect of MIE restrictions: where the GVT was able to identify 54 modes below 5 Hz, the MIE simulation could identify only 22. Other issues addressed through this ground test program were data management of large data sets, extraction of modal properties from data with high modal density, and system identification using a limited number of sensors. Finally, a filtering process was developed to remove phase shift among data sets collected through a multiplexed data acquisition system. If large numbers of sensors were to be approved for an on-orbit MIE, a multiplexed data acquisition system might be necessary.

Significance: The successful implementation of on-orbit MIE tests will depend on careful planning. Analytical simulations can be used extensively for such planning, but laboratory implementation with actual hardware has highlighted realistic potential problems and has allowed researchers to develop techniques for overcoming them.

Future Plans: Further laboratory simulations of MIE are not planned at this time; however, analysis of the extensive data set continues, with particular emphasis on identifying potential nonlinear effects associated with modal interactions. Analytical simulations in support of MIE are on-going.

Figure 66 (a).

LABORATORY SIMULATIONS DEMONSTRATE FEASIBILITY OF ON-ORBIT MODAL TEST

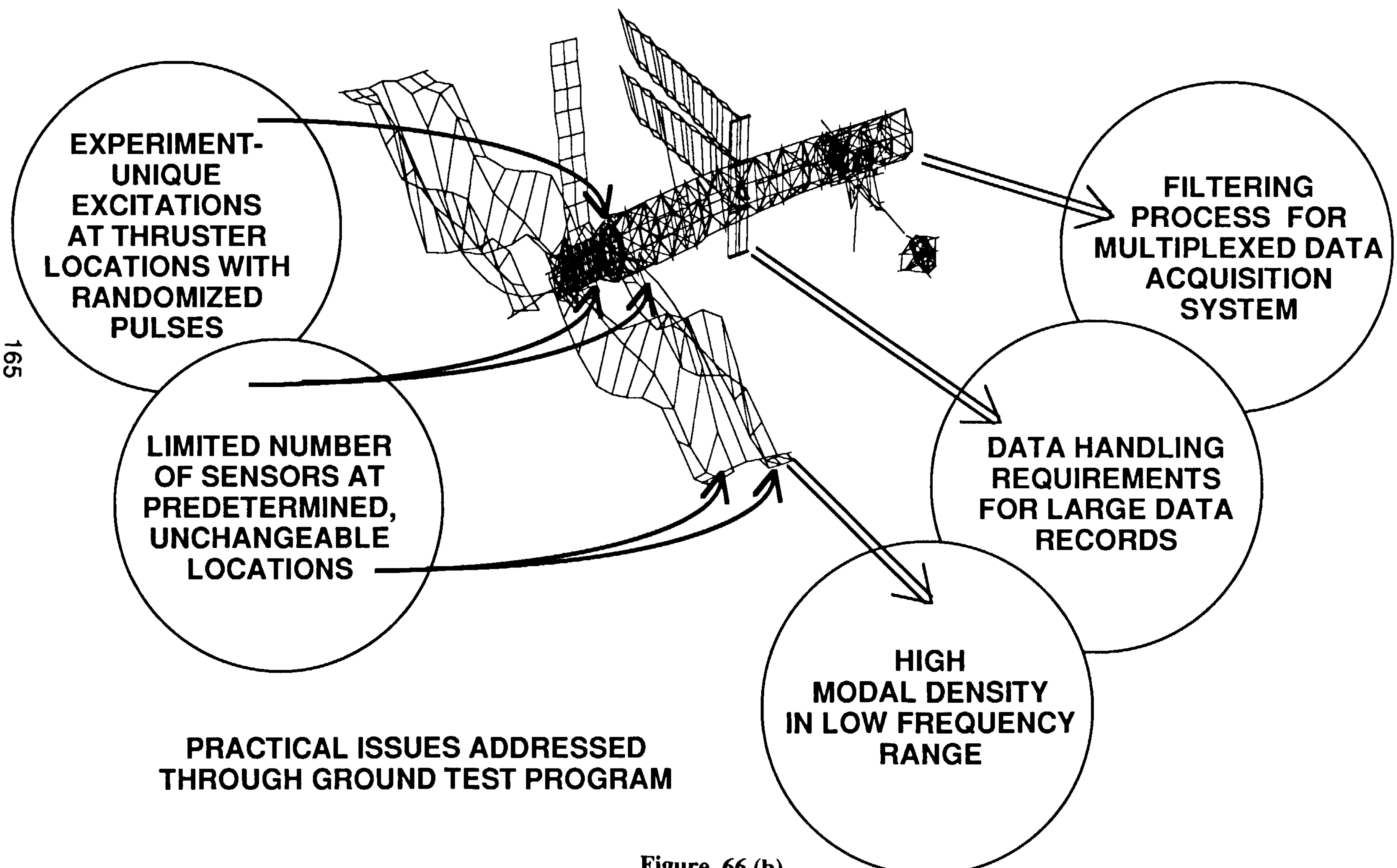


Figure 66 (b).

MODEL REDUCTION PROCEDURES IMPLEMENTED FOR TEST/ANALYSIS CORRELATION

Paul E. McGowan, A. Filippo Angelucci, Mehzad Javeed (LESC)

RTOP 590-14

Research Objective: To implement procedures for reducing finite element models (FEM) of large space truss structures to allow correlation of dynamic test/analysis results.

Approach: Dynamic test/analysis correlation is traditionally limited to comparisons of modal parameters, primarily frequencies and mode shapes, since terms from the mass and stiffness matrices cannot be explicitly verified. However, the FEM and test results cannot be directly compared since the FEM often contains many more degrees-of-freedom (DOF) than responses recorded in the modal test. One approach to this problem is to reduce the FEM to the size of the number of test DOF through development of a test-analysis model (TAM). As depicted in the figure, the size of the TAM is equal to that of the test model. This provides a one-to-one comparison between test and analysis results required for the post-test correlation phase. In addition, the TAM provides a basis for pre-test selection of sensor locations by indicating the expected correlation from a given sensor set.

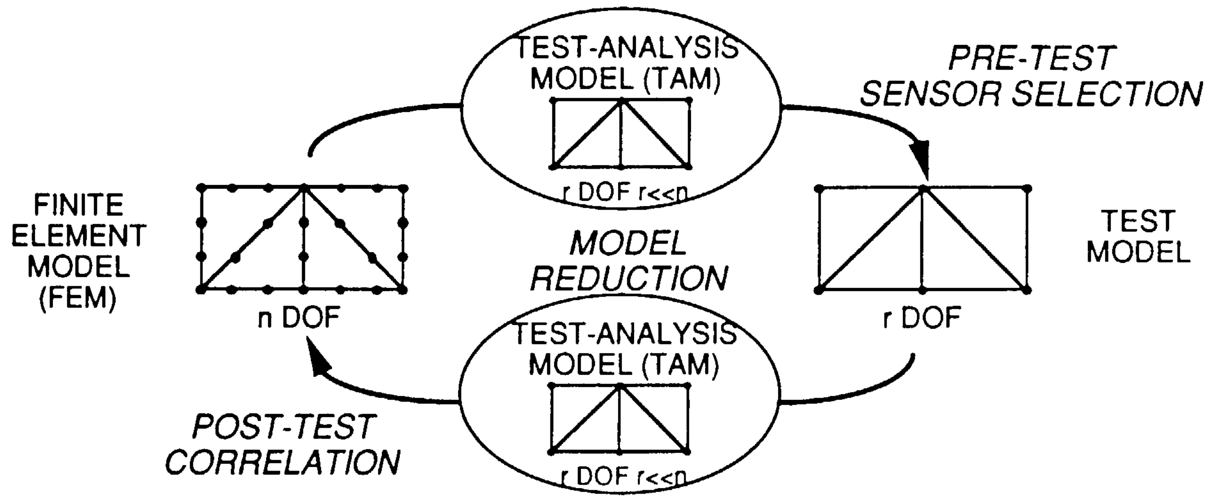
Accomplishment: Several model reduction procedures previously developed in the literature have been implemented in MSC/NASTRAN as DMAP alters. In order to assess and effectively use the reduced models the accuracy of each reduction procedure must be established. A study of reduced model accuracy was performed using a ten-bay laboratory truss structure. This structure was previously characterized with an accurate FEM, thus any discrepancies occurring between the reduced model and the original FEM could be attributed directly to the reduction technique. Comparison of frequency errors resulting from two reduced models, namely Guyan and Improved Reduced System (IRS) reductions, are shown. As indicated in the figure, the original FEM contains 360 DOF while the TAM model contains only 14 DOF located at the truss mid-frame and truss tip. This massive reduction is representative of limited number of sensors on an on-orbit spacecraft. A significant finding was the ability of the IRS reduction to predict the truss axial mode (mode 6) even though no axial measurements were included in the TAM sensor set.

Significance: Test/analysis correlation is an important aspect of the verification of analysis models which are used to predict on-orbit response characteristics of large space structures. Due to the limited availability of on-orbit test data, the increased utilization of ground test data in the correlation process is important. The comparison of the TAM of the structures utilized in this study indicate that IRS method produced reduced FEM which are considerably improved over the Guyan reduced FEM.

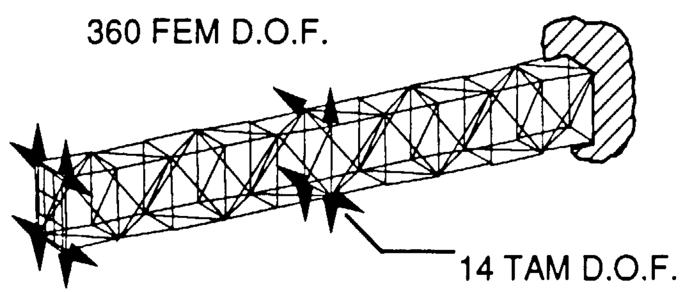
Future Plans: Continue evaluation of model reduction methods applied to more complex structures, with emphasis on IRS. Establish criteria for selection of model reduction techniques applicable to a range of structural components and structural systems.

Figure 67 (a).

MODEL REDUCTION PROCEDURES IMPLEMENTED FOR TEST/ANALYSIS CORRELATION RESULTS



TEN-BAY TRUSS STRUCTURE



FREQUENCY ERROR (%)

MODE NO.	STATIC REDUCTION	MODIFIED REDUCTION
1	0.016	0.006
2	0.021	0.006
3	0.839	0.001
4	3.356	0.002
5	4.756	0.004
6	*	0.348
7	9.803	0.190
8	*	3.413
9	*	10.577

* DID NOT PREDICT THE MODE

Figure 67 (b).

EARLY MODAL IDENTIFICATION EXPERIMENT FEASIBILITY DETERMINED

Z.N. Martinovic (AMA), S.E. Tanner, A.E. Stockwell (LESC) and P.A. Cooper

RTOP 590-14

Objective: The objective of this research was to determine the feasibility of conducting an early Modal Identification Experiment (MIE) during the second build flight (SC-2) of *Space Station Freedom (SSF)*. Specifically, the goal was to determine whether a viable MIE test could be performed while SC-2 was in a mated configuration with the space shuttle orbiter, using the orbiter thruster firings for excitation.

Approach: During the second build flight of *SSF*, data lines across the unpressurized berthing adapter (UBA) will be necessary when the shuttle and station are in joint-flight so astronauts can verify the operation of station subsystems. If those lines were also used to collect dynamic measurements, an early MIE could be conducted. Shuttle thruster firings will be restricted to short pulses, under the so-called "alt mode" of control, when the orbiter is connected to *SSF*. However, these short pulses should provide sufficient excitation of the coupled system. Transient responses were calculated in this study at 58 target sensor locations on *SSF*, using a NASTRAN finite element model of the station attached to a simplified rigid-body model of the orbiter. The transient responses were then corrupted with errors simulating operational noise, digitzation errors, sampling delays, and individual sensor scale factor errors. Modal identification was performed on the corrupted free-decay time histories using the Eigensystem Realization Algorithm.

Accomplishment: Through this analytical study, the alt mode firings of the shuttle thrusters have been shown to provide sufficient excitation so that the frequency and damping of the photovoltaic (PV) arrays and thermal radiators can be determined. However, the small number of sensors targeted for PV arrays limits the unique identification of PV mode shapes. Further, the presence of the orbiter's large mass attached to *SSF* has the effect of altering the dynamic characteristics of the truss modes. Understanding was enhanced on the practical limitations of reduced sensor sets and high levels of operational noise on uniquely determining closely-spaced modes for a coupled *SSF*-orbiter system.

Significance: The successful implementation of a MIE test early in the *Space Station Freedom* build sequence would provide both engineering and research benefits. Early validation of analytical models of the PV arrays could benefit *SSF* program since these models are used for predicting loads and determining operational constraints. Experimentally quantifying the on-orbit load transmissibility of the UBA would also benefit the program because the UBA will be used in all construction stages through SC-5. In addition, acquiring on-orbit dynamic measurements of an early SSF configuration would add to a database which could later be used for research studies related to component mode synthesis and system identification.

Future Plans: Further studies are planned on the effect of errors in predicted frequency, damping, and mode shape on the accuracy of calculated member loads on *SSF*, in addition to studies on the effectiveness of various excitation pulses from the orbiter.

Figure 68 (a).

EARLY MODAL IDENTIFICATION EXPERIMENT FEASIBILITY DETERMINED

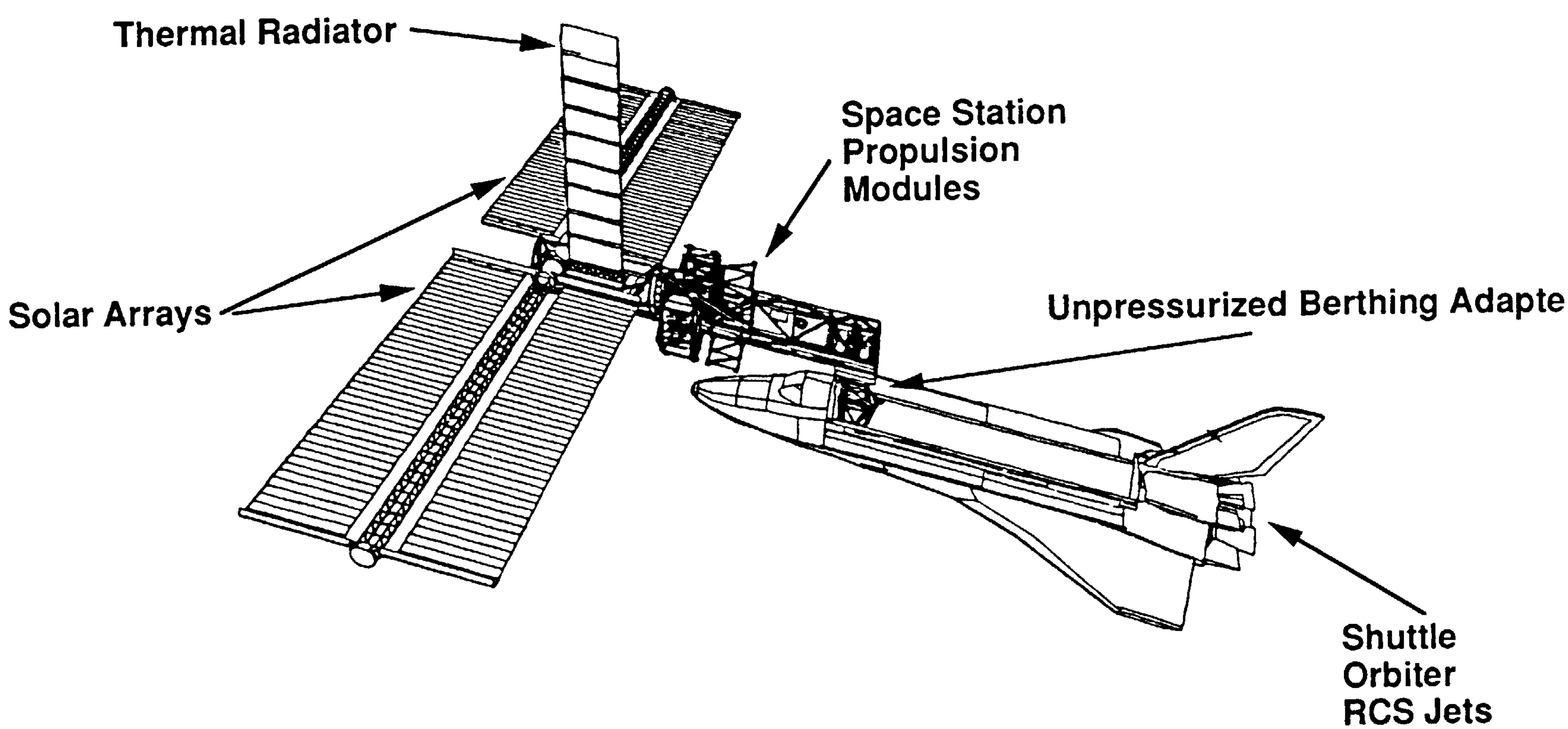


Figure 68 (b).

FLEXIBLE MANIPULATOR TESTBED INSTALLED

Mercedes C. Reaves, Jer-Nan Juang, and Haluk Elci (Columbia Univ.)

RTOP 506-43-41

Research Objective: A new flexible manipulator testbed in the Spacecraft Dynamics Branch has been installed with the primary objective of conducting advanced multibody dynamic test and analysis. Verification of concepts and ideas by experimental demonstrations is of fundamental importance. Theoretical breakthroughs gain final acceptance by experimental evidence and applications, which aids assimilation by industry, and forms the bridge between theory and practice.

Approach: The seven degree of freedom manipulator (a K-series 807iPH, Type 2 Controller Dextrous Manipulator of Robotic Research Corporation) in the Spacecraft Dynamics Branch is one of the most advanced manipulators currently available. Although its original design is rigid, two easily insertable custom manufactured extension rods convert the manipulator to a flexible one (See figure). With the extension rods inserted the manipulator has a natural frequency as low as 1 Hz resembling a flexible structure. An advanced zero-gravity three degrees of freedom suspension system has been developed in a joint venture between NASA LaRC and Boeing Corp. to support the manipulator in its flexible configuration. The versatility and programmability of the manipulator makes it an excellent testbed for state-of-the-art experiments in many fields such as controls, system identification, vibration supression and nonlinear multibody dynamics.

Accomplishment Description: The manipulator was delivered to the Spacecraft Dynamics Branch on April 27, 1992. It has been successfully installed and several demonstrations programs have been written and tested to determine its functionality. To within the limitations it conforms to the specifications established in terms of programmability, interfacing capabilities, speed, accuracy and repeatability parameters; joint travel and workspace; maximum payload and feedback capabilities.

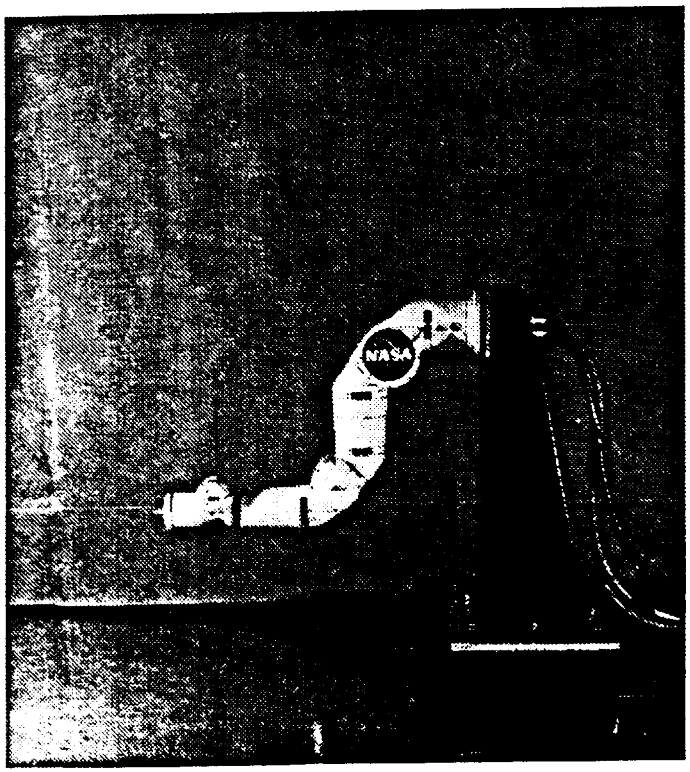
Significance: The manipulator in the Spacecraft Dynamics Laboratory is a very general and versatile testbed. With the extension rods inserted and the zero-gravity 3-D suspension system installed the manipulator represents an extremely general dynamical system: flexible, nonlinear, multybody.

Future Plans:: Initial experiments to validate specific analytical control concepts such as learning control will be conducted with the manipulator in its rigid configuration. Those experiments will build on the knowledge neccesary to move from the rigid body experiments to the flexible manipulator experiments.

Figure 69 (a).

FLEXIBLE MANIPULATOR TESTBED INSTALLED

Rigid Manipulator



Flexible Manipulator

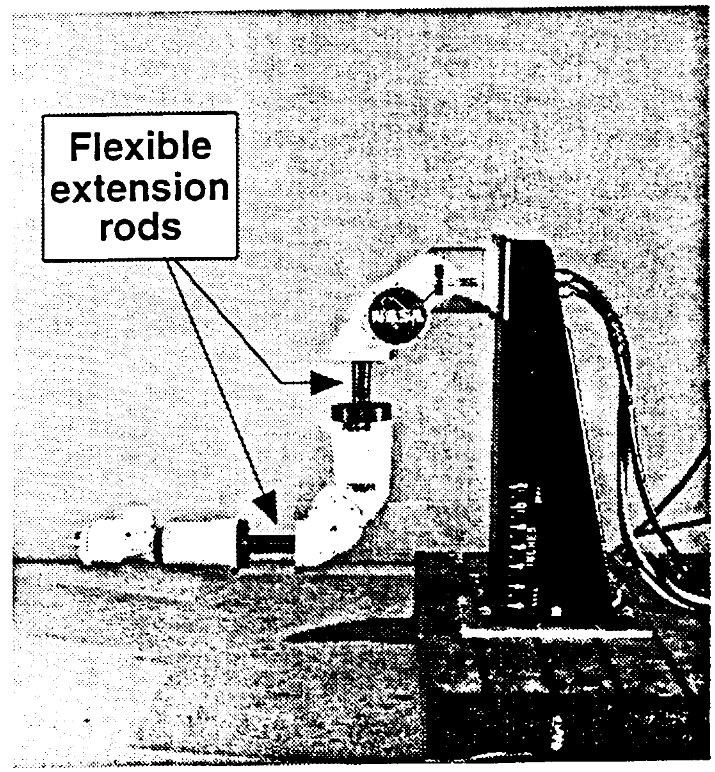


Figure 69 (b).

A NEWLY DEVELOPED OBSERVER/CONTROLLER IDENTIFICATION (OCID) TECHNIQUE SUCESSFULLY PREDICTS AIRCRAFT FLUTTER FROM STABLE CLOSED-LOOP TESTS

Jer-Nan Juang, Minh Phan (LESC) and Anthony S. Pototzky (LESC)

RTOP 506-43-41

Research Objective: Demonstrate the application of a newly developed observer/controller identification (OCID) technique to predict open-loop aircraft flutter from stable closed-loop tests.

Approach: Experimental data was obtained from wind tunnel tests of an aeroelastic model with active flutter control operating. The model, known as the Active Flexible Wing (AFW), has a digital controller which suppresses flutter by properly phased commands to actuators of eight control surfaces on the wing leading and trailing edge surfaces. During flutter suppression control law testing, acceleration signals from sensors distributed on the model were first filtered for antialiasing and then quantized at a 200Hz sample rate. The quantized signals obtained from both sides of the model were then symmetrized in pairs. These symmetrized signals became the inputs to the symmetric and antisymmetric flutter suppression control laws and also the source of the closed-loop response time histories to be used for the identification process. Output signals of the feedback control laws and independent input excitation to the wing provided the remaining time histories necessary for identification of the closed-loop control system. During tests, each of the actuator inputs was excited individually by adding the excitation signal to the feedback control output signal. This procedure allowed the generation of all the responses necessary to identify the multi-input/output control system. The excitation signals themselves were either logarithmic sine sweeps or so-called pseudo-random noise. The excitation signal, the resultant closed-loop response time histories, and the feedback control signal were used with the OCID technique to identify all of the elements of the AFW model including the open-loop system matrices, an observer gain, and the existing controller gains. The flutter mode is then identified by solving the eigenvalues of the open-loop state matrix.

Accomplishment Description: Seven sets of experimental data were used corresponding to different dynamic pressure conditions, 175 pounds per square foot (psf), 200 psf, 230psf, 240psf, 250 psf, 260 psf and 280 psf respectively. The identified flutter mode for the 250 psf condition has an open-loop frequency of 9.06 Hz and 0.26% negative damping, indicating marginal open-loop instability. The identified flutter mode for the 260 psf condition shows an open-loop frequency of 8.78 Hz and 3.34% negative damping, implying greater open-loop instability. The applied excitation signal, the accelerometer sensor signal and the control feedback signal for the 260 psf condition are shown in the figure. The identified observer/controller Markov parameters, which are used to produce the estimated open-loop response, are also exhibited in the figure. The final 280 psf condition was identified to have an open-loop frequency of 8.76 Hz and 5.73% negative damping. Comparison of the identified results with the analytical results shows excellent agreement in frequencies and damping, indicating a coalescing mode switch in frequency.

Significance: The technique has been successfully applied to an aircraft structure operating in an aeroelastic environment. The technique was demonstrated to be capable of identifying a potential open-loop flutter of an aircraft which is operating in a stable closed-loop control condition.

Future Plans: This method will be compared with other existing methods including a recently developed aircraft controller performance evaluation technique. Joint efforts between the aeroelasticity and spacecraft dynamics disciplines will be continued.

Figure 70 (a).

A Newly Developed Observer/Controller Identification (OCID) Technique Successfully Predicts Aircraft Flutter From Stable Closed-Loop Tests

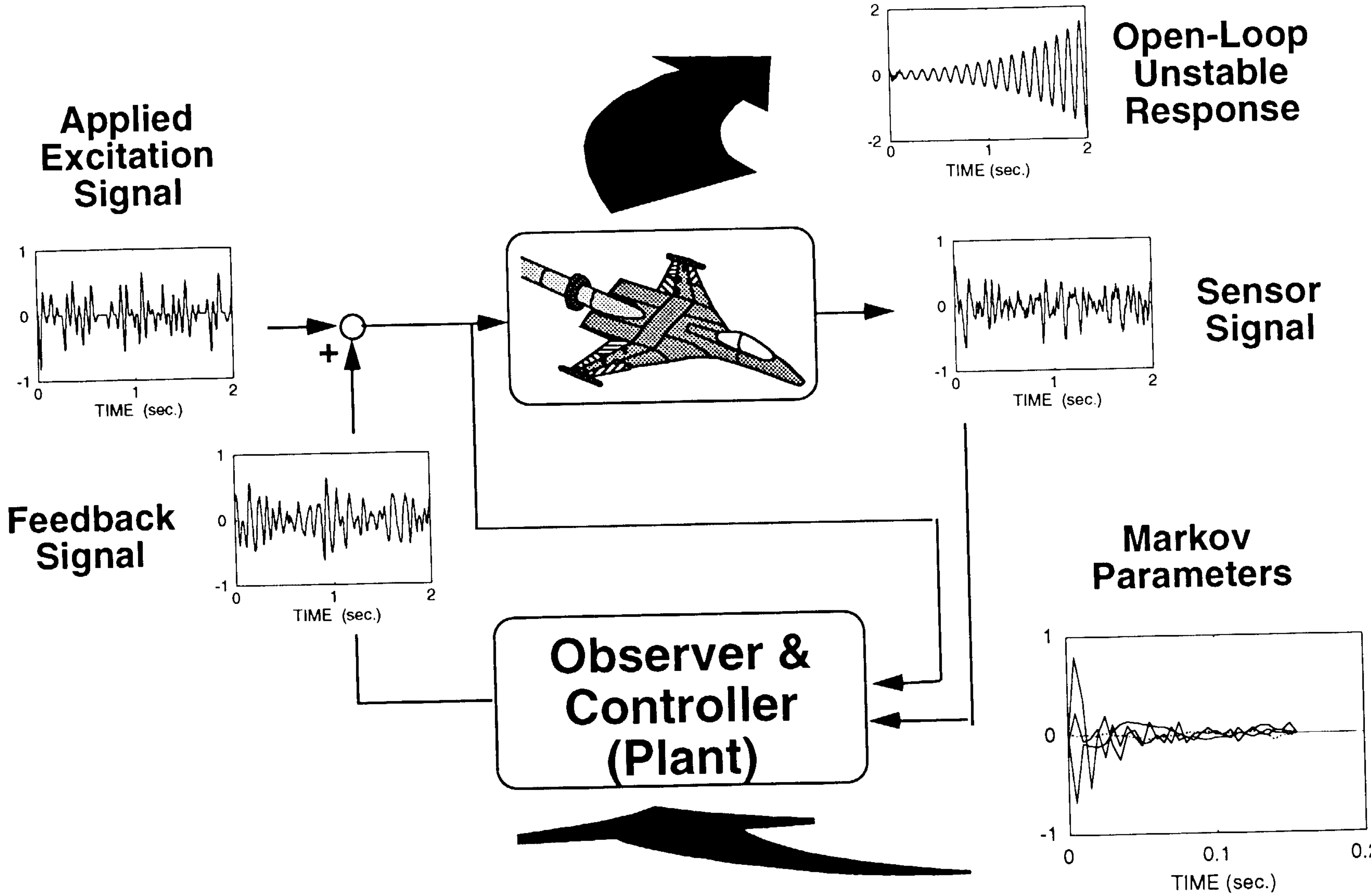


Figure 70 (b).

ADAPTIVE CONTROL USING ON-LINE IDENTIFICATION DEMONSTRATED

Lucas G. Horta and Chris A. Sandridge (LMSC)

RTOP 590-14

Objectives: Identification of the forward and inverse dynamics for on-line health monitoring and adaptive controls. Demonstrate use of inverse dynamics for vibration control of flexible structures.

Approach: A recursive, least squares algorithm that identifies parameters based on an observer formulation has been programmed for real-time implementation on a VAX 3200 computer. The standard identification problem seeks to find, given input and output data, an analytical representation of the system. Depending on how the input and output data is fed into the algorithm, two models can be identified. The *forward* model estimates the output of the system based on a given input and the *inverse* model computes an input that will produce a given output. Once the inverse model is identified, it can be used to compute control inputs by supplying the model an appropriate desired response. This is the basis for the control formulation demonstrated in the laboratory.

The experimental set-up uses an L-shaped aluminum truss with two piezoelectric actuators. Outputs from near-collocated strain gages are used for identification. Actuator commands and measurements from strain gages are updated at a sampling rate of 60 Hz. The maximum sampling rate is limited by the number of observer parameters in the model (user defined), the number of input/output pairs, and the speed of the real-time computer. When prescribing a desired system response, one must avoid abrupt changes in the response because they required unrealistic commands. In this particular example the strain output is gradually commanded to zero.

Accomplishments: On-line identification of the forward and inverse dynamics has been experimentally demonstrated. Typical free response data for one strain gage is shown in the top right plot and the controlled counterpart is shown underneath. Implementation is divided into three stages, first is the open loop excitation to identified the forward model, followed by identification of the inverse model, and finally the controlled response given a desired system response. Procedures to disable the controller when the response signals are within the noise threshold have been implemented.

Significance: Ability to identify and control a system without the need for a priori models and/or control laws is extremely important in general. Health monitoring and control of systems that may exhibit configuration changes while in operation would certainly benefit from this technology.

Future Plans: Efficient computational procedures to accelerate parameter updates will permit faster sampling rates and more flexibility with current computing capability. Implementation using a faster computer is planned and some of the numerical properties of the current configuration need to be addressed.

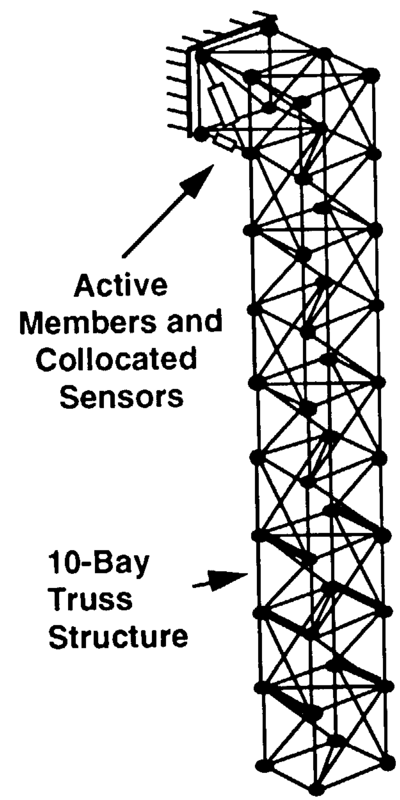
Figure 71 (a).

ADAPTIVE CONTROL USING ON-LINE SYSTEM IDENTIFICATION DEMONSTRATED

Process

- Random excitation using active members
- Forward and inverse model identified on-line during excitation
- Inverse model used for controls

Laboratory Model



Test Results

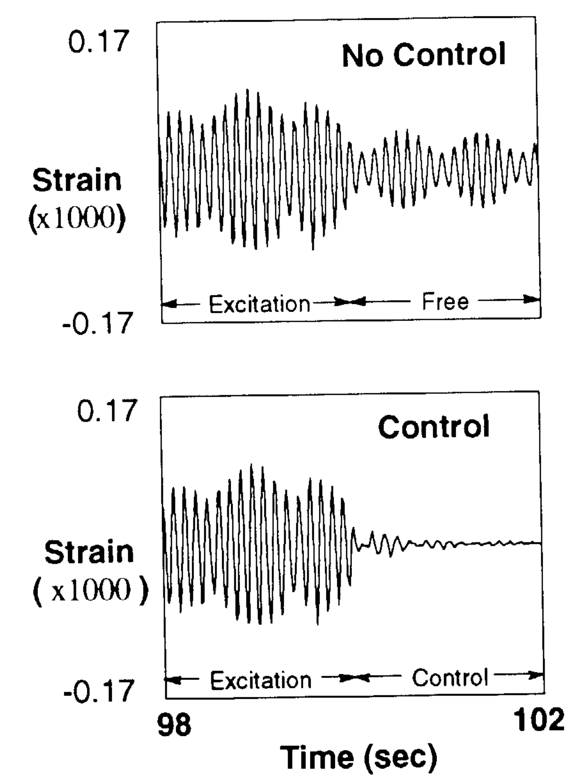


Figure 71 (b).

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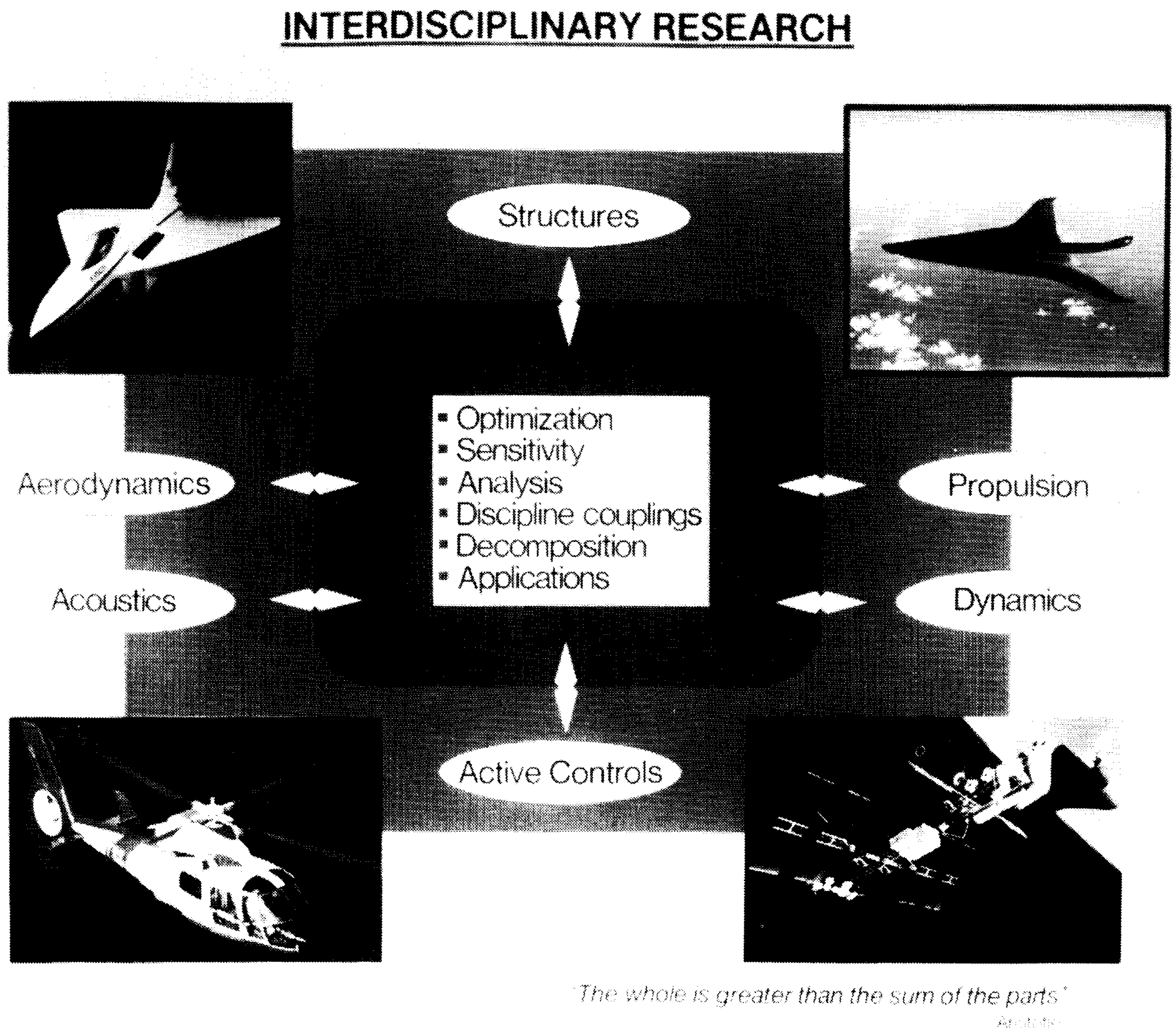

Figure 72.

176

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INTERDISCIPLINARY RESEARCH FUTURE PLANS (FY 93-97)

GOAL

DEVELOP COMPREHENSIVE METHODOLOGY FOR OPTIMAL MULTI- DISCIPLINARY DESIGN

KEY OBJECTIVES

- METHODOLOGY

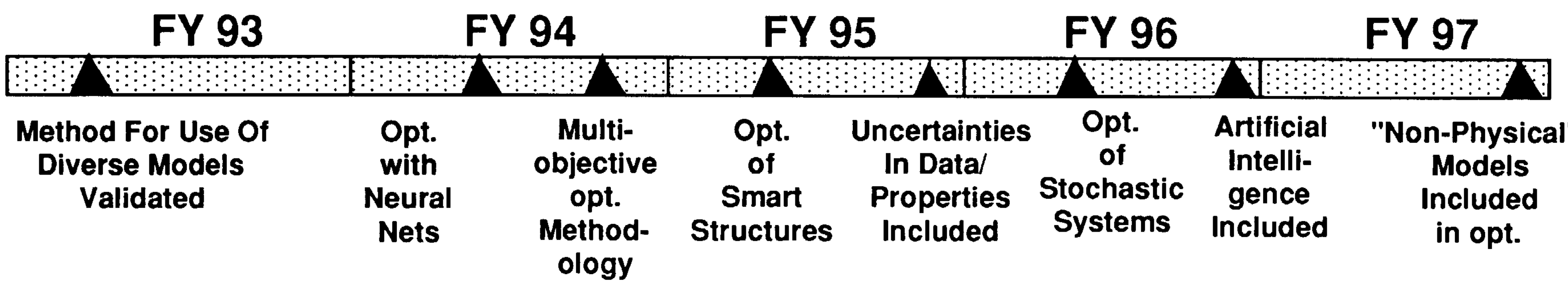


Figure 73 (a).

INTERDISCIPLINARY RESEARCH FUTURE PLANS (FY 93-97)

GOAL

DEMONSTRATE OPTIMAL DESIGN

KEY OBJECTIVES

- HIGH SPEED CIVIL TRANSPORT

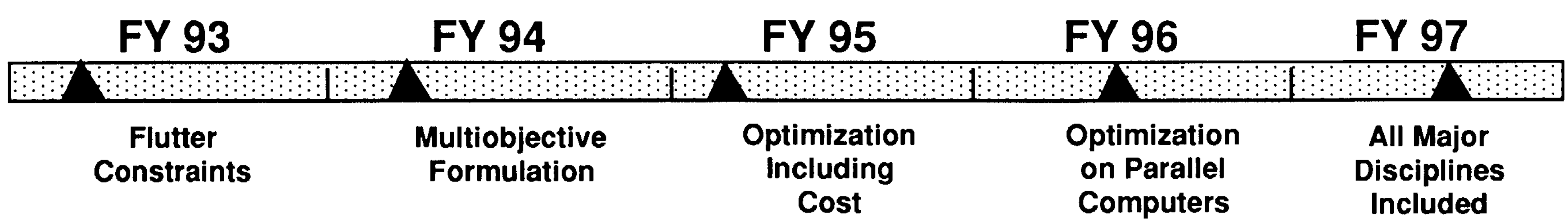


Figure 73 (b).

INTERDISCIPLINARY RESEARCH FUTURE PLANS (FY 93-97)

GOAL

DEMONSTRATE OPTIMAL DESIGN

KEY OBJECTIVES

- ROTORCRAFT

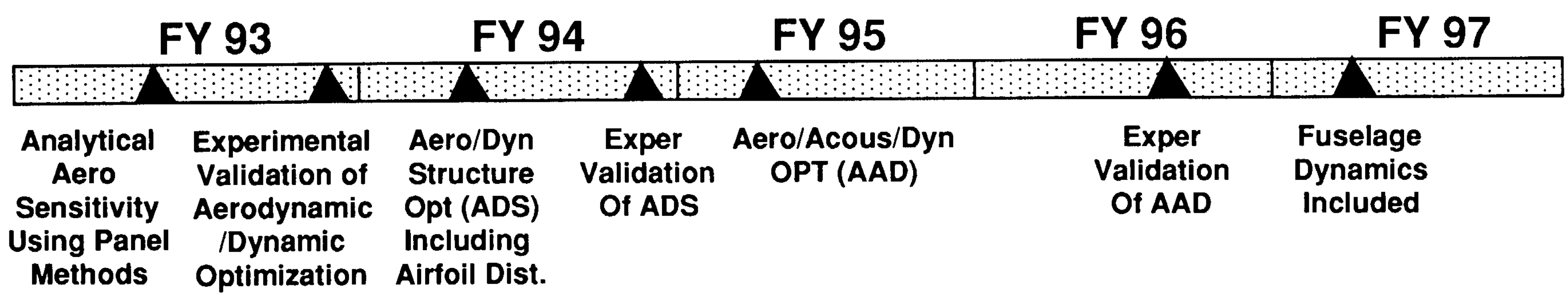


Figure 73 (c).

OPTIMIZATION OF WING BENDING MATERIAL WITH FLEXIBLE LOADS FOR HiSAIR MACH 2.4 TRANSPORT CONFIGURATION

J.-F. M. Barthelemy
P. G. Coen, Vehicle Integration Branch
Aeronautics Directorate

G. A. Wrenn and A. R. Dovi
Lockheed Engineering and Sciences Corporation

L. E. Hall, Unisys Corporation

RTOP 505-63-50

Research Objective: The HiSAIR/Pathfinder project aims at demonstrating an approach to design integration based on disciplinary analysis and sensitivity analysis capabilities and formal optimization methodology.

Approach: The initial focus of the Pathfinder activity is a three discipline integration exercise that is to maximize aircraft performance with respect to structural and basic wing configuration variables while satisfying constraints on structural integrity and minimum performance requirements. Basic analysis modules include the following Langley-developed computer programs: ELAPS for structural analysis of a plate model of the aircraft, the linear aerodynamics code WINGDES for prediction of airloads and drag due to lift and FLOPS for estimation of basic performance characteristics. Optimization is based on the OPTDES commercial nonlinear optimization package while data management is largely done with RIM, a relational database.

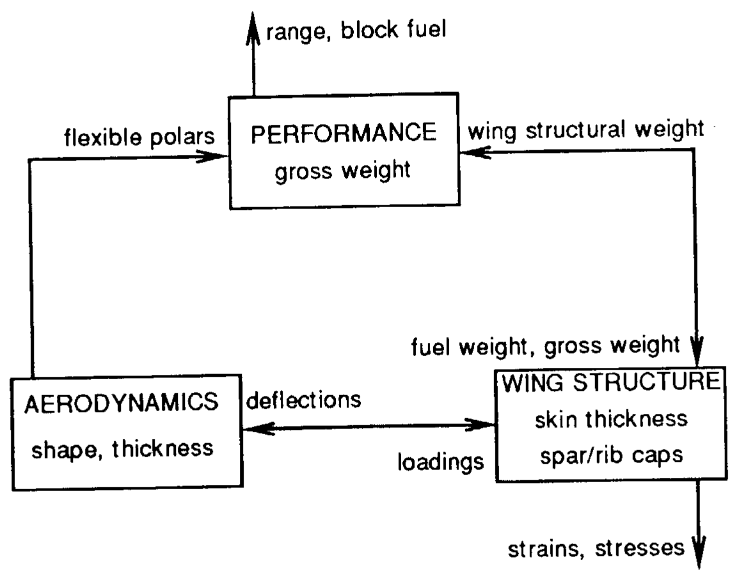
Accomplishment Description: Design studies have been conducted with a M 2.4 transport configuration. The optimization system currently includes aerodynamic and structure modules and provides the capability for minimum weight structural design; analysis and sensitivity analysis take into account the elastic redistribution of loads. The figure shows final weight of bending material (wing skins and spar and rib caps) for combinations of two advanced materials (aluminum and titanium alloys) and two spar layouts (swept spars are straight and intersect the fuselage axis at an angle, cranked spars have a bend at the wing break and are perpendicular to the fuselage axis in the inboard section of the wing). Each combination is designed for three different sizes of the square wing panels. The overall trend is for bending material weight to decrease as the panel size decreases since the panels become less prone to buckling and thinner face sheet thickness can be used. All other things being equal, the aluminum wings are lighter than the titanium ones on account of the better specific stiffness of aluminum. Also, all other things being equal, cranked spar wings are slightly heavier than straight spar ones because, in the inboard section of the wing, the cranked spars are back from the straight spars, in an area where the overall airfoil thickness is lower.

Significance: When completed, this system will provide for a first implementation of a design tool that considers directly the impact that aerodynamic and structural design have on aircraft performance. The integration approach used is generic however and the demonstrated methodology is expected to be applicable to any complex design problem.

Future Plan: Work is underway to test a system incorporating both aerodynamic and performance modules and that permits aircraft configuration design. Then all three modules will be integrated together permitting simultaneous configuration and structural design for optimum performance. Also, the current system performing minimum weight design for fixed configuration under static aeroelastic constraints is being augmented with a module predicting flutter instability so that dynamic aeroelastic constraints can be included.

Figure 74 (a).

Optimization of Wing Bending Material with Flexible Loads for HiSAIR Mach 2.4 Transport Configuration



- Three disciplines combined to include important coupling effects
- Initial implementation uses linear aerodynamic, performance and structural analyses

- Currently performs minimum weight design under multiple flexible load cases
- Stress, strain and buckling constraints of wing skin panels and spar and rib caps

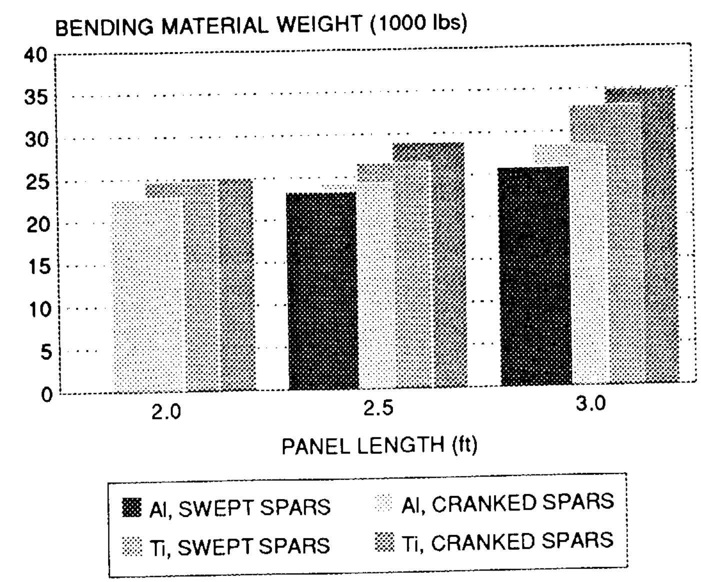


Figure 74 (b).

AERODYNAMIC SENSITIVITY ANALYSIS USING AUTOMATIC DIFFERENTIATION DEMONSTRATED FOR HELICOPTER ROTORS

Joanne L. Walsh, Y. Danny Chiu (LESC), and Linda B. Booth (Unisys Corp.)
Interdisciplinary Research Office

RTOP 506-63-36

Research Objective: To develop and validate methods for efficient calculation of aerodynamic sensitivity derivatives for incorporation into integrated multidisciplinary optimization procedures for helicopter rotor blades.

Approach: The approach is to use the ADIFOR (Automatic Differentiation in FORTRAN) code to generate aerodynamic sensitivity derivatives of a rotor blade in axial and forward flight. ADIFOR is a preprocessor that systematically implements the chain rule of differentiation to generate code for the derivatives of functions calculated by a FORTRAN program. ADIFOR provides exact results for aerodynamic sensitivity derivatives. The first step is to use ADIFOR to generate aerodynamic sensitivity derivatives of a lifting line code. These derivatives are compared with analytical and finite difference derivatives. The second step is to use ADIFOR to generate derivatives for a vortex panel code.

Accomplishment Description: ADIFOR has been used to generate derivatives in a lifting line code for a rotor blade in axial flight for the blade model shown in the figure. These derivatives compare well with both previously derived analytical and finite difference derivatives. The figure shows the derivative of the lift-drag ratio with respect to taper ratio for finite difference, ADIFOR and analytical methods. The ADIFOR and analytical method derivatives are exact. The finite difference derivative is approximate and step-size dependent. The total time required to obtain the analytical result using ADIFOR and the analytical method was only about two-thirds of the time required by the finite difference approach.

Significanc: Results indicate that ADIFOR is a promising tool to generate analytical aerodynamic derivatives when it is not possible to derive formulae for analytical derivatives. ADIFOR derivatives require less CPU time to compute than derivatives obtained using a finite difference method. An investment of time in preprocessing the aerodynamic code through ADIFOR to obtain the code for the aerodynamice sensitivity derivatives may lead to a significant payoff in both time saving and accuracy . Once the codes are coupled, the new code can be used for incorporation into integrated multidisciplinary optimization procedures for helicopter rotor blades.

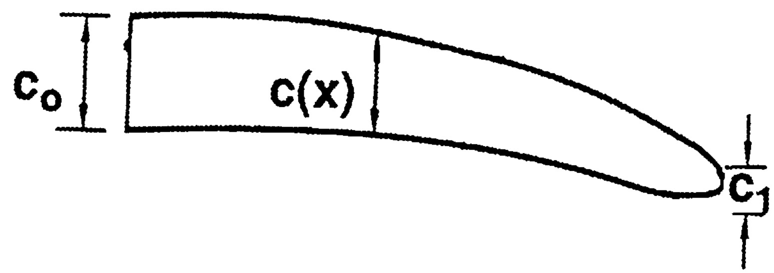
Future Plans: Extend the ADIFOR approach to the vortex panel analysis.

Figure 75 (a).

AERODYNAMIC SENSITIVITY ANALYSIS USING AUTOMATIC DIFFERENTIATION DEMONSTRATED FOR HELICOPTER ROTORS

Objective: Develop aerodynamic sensitivity analysis procedures for helicopter rotors by using Automatic Differentiation in FORTRAN (ADIFOR)

top view of blade model $\quad l = C_1 / C_0$ = taper ratio



Example: Derivative of lift-drag ratio with respect to taper ratio

METHOD	$\partial(C_L / C_{D_i}) / \partial l$	**CP TIME (SEC)**
Finite Difference (Δl = .01)	0.094358	84
ADIFOR	0.094858	59
Analytical	0.094858	53

Figure 75 (b).

OPTIMAL ACTIVE STRUT PLACEMENT

Sharon L. Padula

Chris A. Sandridge, Lockheed Engineering and Sciences Company

RTOP 506-43-41

Research Objective: To improve damping in a large flexible space structure by replacing selected truss members with active struts that can sense and dissipate energy.

Approach: An important consideration in the design of a large space structure is determining the optimal number and location of active or passive damping elements. This is a challenging optimization problem when either the number of candidate locations or the number of target modes is large.

A procedure for active strut placement using integer programming was developed. The search for the best locations is based on strain energy calculated at each location and for multiple normal modes of the structure. The procedure is implemented by combining a linear integer programming code (LINDO) with a structural finite element code (NASTRAN) to create general purpose active strut placement software.

Accomplishment: The active strut placement procedure was tested by applying it to the Phase-1 CSI Evolutionary model (shown in the center of the figure). Any of the 1507 aluminum truss members can be removed and replaced with a piezoelectric device which senses axial strain and compensates by producing strain in the opposite direction. For instance, the best eight locations are indicated by heavy lines on the magnified views of the truss structure. Adding more than eight active struts (e.g. 16 or 32) improves the damping in all ten target modes as shown in the lower half of the figure.

The active strut placement algorithm can be validated experimentally. The optimal strut placement is compared to a manual strut placement which is based on engineering judgment. Both configurations are tested in the Space Structures Laboratory and the output auto-spectra are compared to determine which set of eight locations provides the most damping in ten target modes.

Preliminary laboratory tests were completed. The test results indicate that active struts improve damping significantly. However, the results suggest that the current active struts do not perform consistently and that the finite element model does not adequately represent the laboratory structure. These concerns must be addressed before testing can resume.

Significance: The strut placement software can predict the best locations for active struts (or passive damping treatment) on any truss structure for which a finite element model exists.

Future Plans: Optimal and manual placement of active struts will be repeated for the Phase-2 Evolutionary model.

Figure 76 (a).

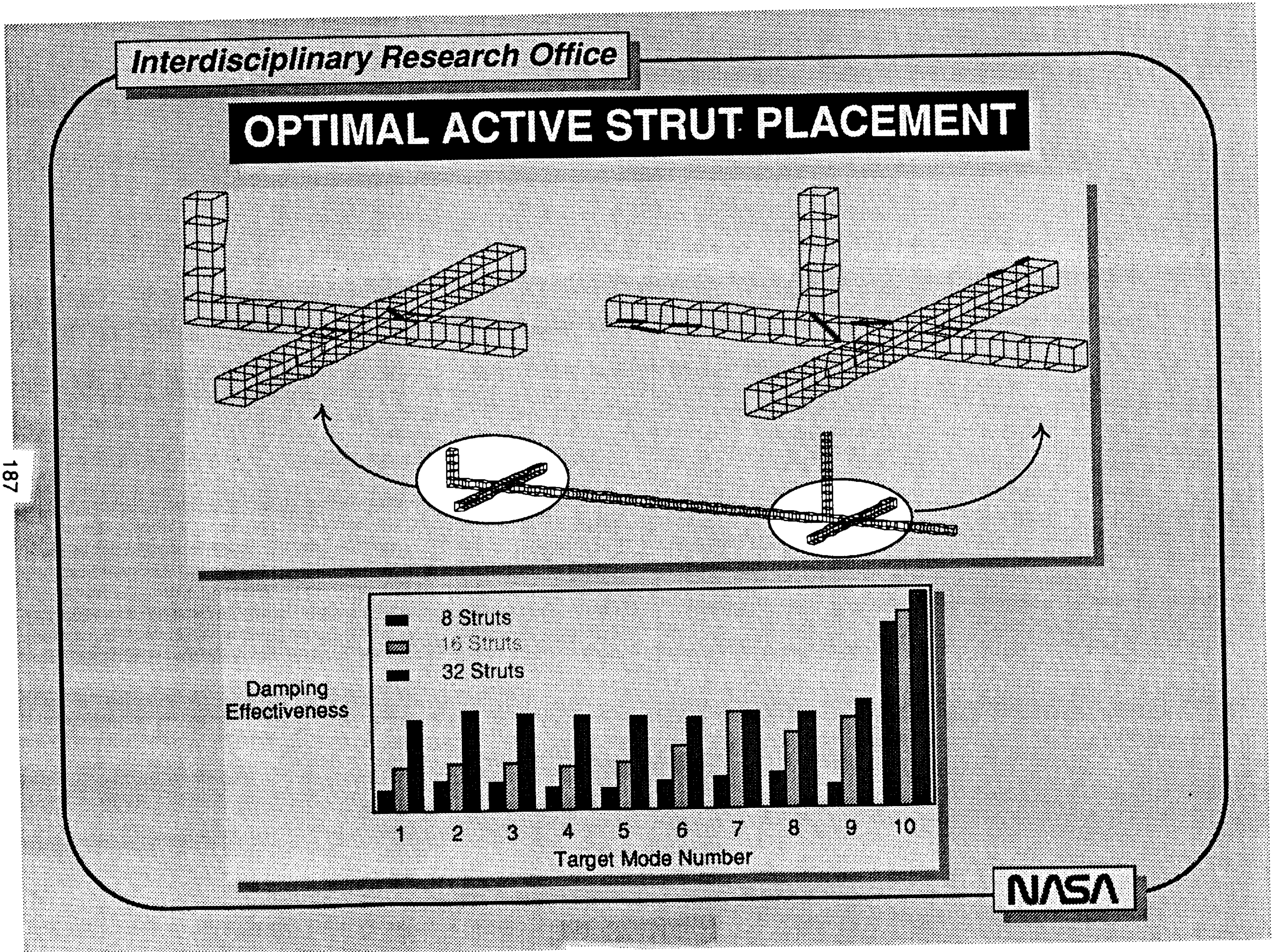

Interdisciplinary Research Office
OPTIMAL ACTIVE STRUT PLACEMENT
8 Struts
16 Struts
32 Struts
Damping Effectiveness
1
2
3
4
5
6
7
8
9
10
Target Mode Number

Figure 76 (b).

CONTROLLED SPACE STRUCTURE DESIGN DEMONSTRATES STRENGTHS OF GLOBAL SENSITIVITY APPROACH

Sharon L. Padula

Benjamin B. James, Lockheed Engineering and Sciences Company

RTOP 506-43-41

Research Objective: To develop multidisciplinary optimization methods for aerospace design problems considered intractable using conventional optimization methods.

Approach: The four step method for design of a controlled space platform is indicated in the diagram. (1) The mass and performance of the spacecraft is computed using current values of each design variable. The iteration between structures and control computer codes is required because some outputs of each code form inputs to the other code. These coupling terms are guessed at first and improved with iteration. (2) When the iteration converges, local (i.e. single- discipline) derivatives are calculated. That is, the sensitivity of each analysis output with respect to its input is determined. (3) Global Sensitivity Equations (GSE) are used to calculate the global derivatives. Global derivatives estimate the change in the coupled structures-controls analysis caused by a change in any design variable. (4) The optimizer updates the design variables using a systematic search algorithm. The search is based on a linear approximation to the coupled structures-control analysis to save computational effort.

Accomplishment: The GSE approach was successfully tested on a problem with 150 design variables including truss sizing variables and controller gains. Individual design variables directly influenced either structural analysis or controls analysis and indirectly influenced the global design. Traditional optimization methods have difficulty handling this class of problem because the noise in the coupled structures-controls analysis inevitably contaminates finite difference estimates of global derivatives. Moreover, traditional methods would require at least twice as much computational effort as the GSE approach.

Significance: This research develops methods and software which can be applied to other multidisciplinary aerospace designs.

Future Plans: The HiSAIR/Pathfinder project will apply this method to an aircraft design with more disciplines and more complex coupling between disciplines.

Figure 77 (a).

CONTROLLED SPACE STRUCTURE DESIGN DEMONSTRATES STRENGTHS OF GLOBAL SENSITIVITY APPROACH

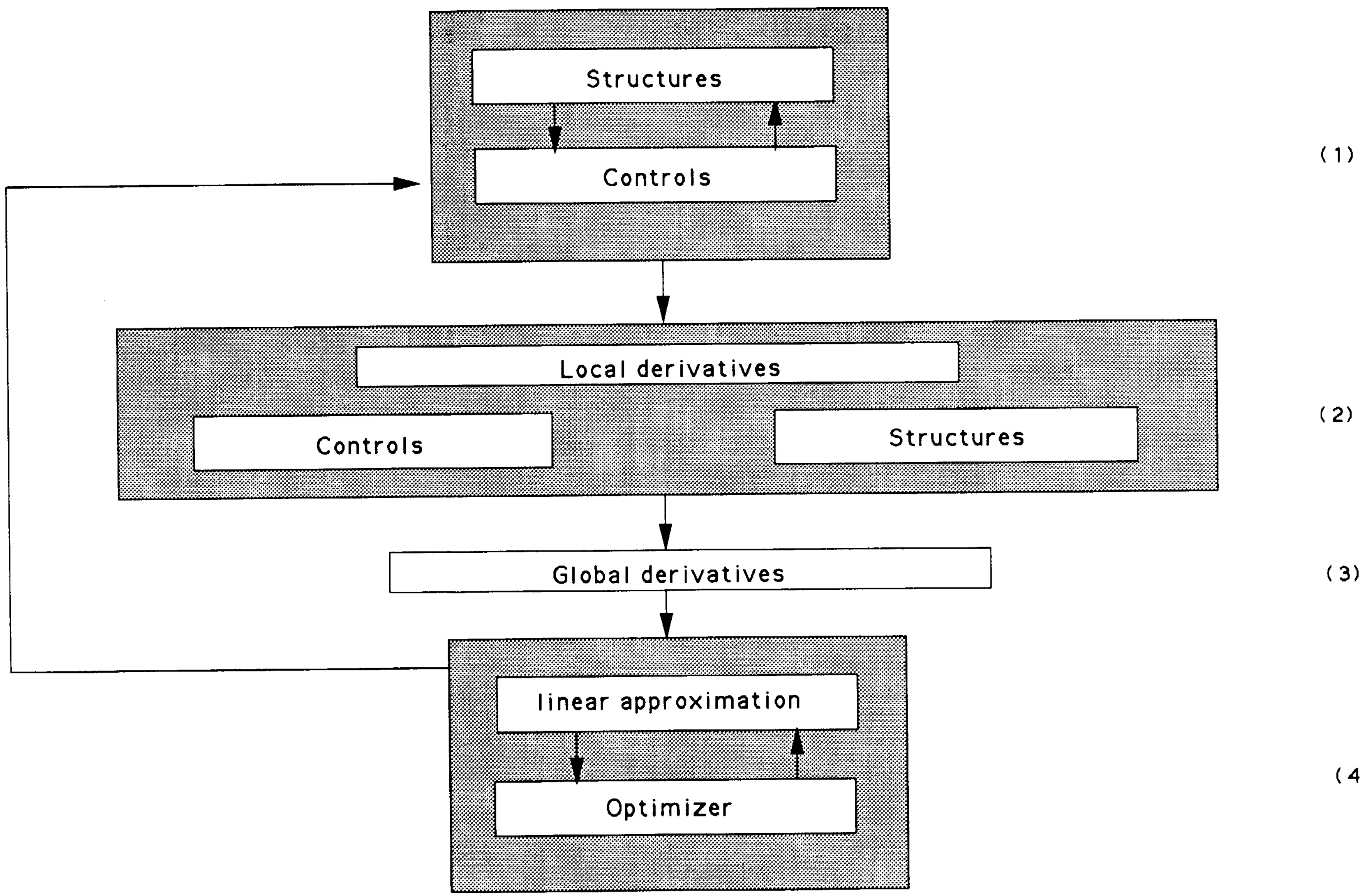


Figure 77 (b).

AUTOMATIC DIFFERENTIATION ADAPTED AND EVALUATED AS A TOOL FOR ENGINEERING DESIGN

Jean-Francois M. Barthelemy
and
Laura E. Hall (Unisys Corporation)

RTOP 505-63-50

Research Objective: Automatic Differentiation (AD) is a technique which enables one to automatically derive a computer program which performs sensitivity analysis of an engineering system, starting from an existing computer program performing the analysis of the system. If the original program calculates a set of dependent (output) variables from a set of independent (input) variables, the modified program calculates the derivatives of the dependent variables with respect to the independent variables. AD is not an automatic implementation of finite differencing which would produce approximate derivatives. It is neither an implementation of symbolic manipulation which tends to result in convoluted expressions for the derivatives. Rather, it is a systematic implementation of the chain-rule of differentiation at a cost generally lower than conventional finite differencing. The objective of this research is to evaluate AD as a tool to produce the derivatives necessary for engineering design and optimization.

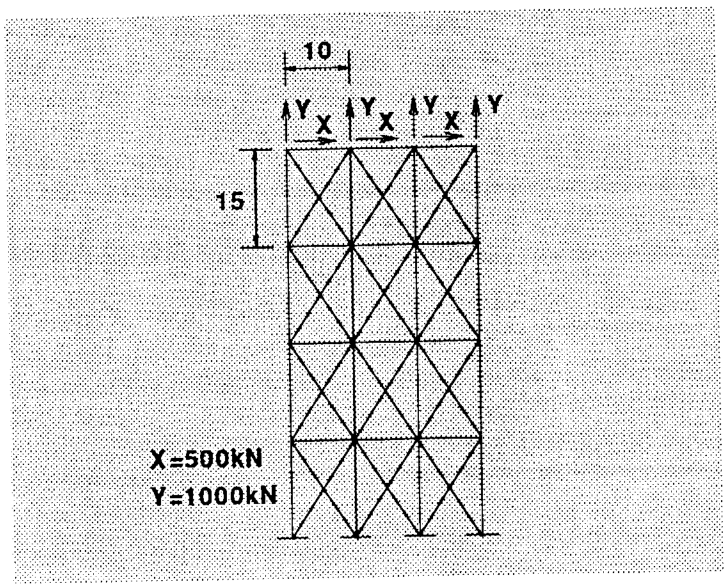
Approach: To implement AD, one modifies the original program by insertion of specialized instructions which identify relevant independent and dependent variables. The program is then further modified automatically by a preprocessor which augments it to calculate derivatives. The modified program is compiled conventionally, linked with a special run-time library and can then be executed.

Accomplishment Description: This initial phase of the research demonstrated the use of the code GRESS, developed at Oak Ridge National Laboratory. It was applied with the finite element analysis program STAP which performs static analysis of space trusses. The example discussed on the slide is a planar truss for which the independent variables were the 52 member cross-section areas while the dependent variables were 113 quantities including structural weight, nodal displacements and member stresses. The resulting set of derivatives were generated in 7 seconds on a SUN SPARCstation 1+ while generating the corresponding derivatives by finite difference would have taken 36 seconds or 5 times longer.

Significance: Engineering design and optimization require sensitivity information. For some engineering disciplines, analytical techniques exist to generate those sensitivities; for most disciplines, however, those derivatives have not yet been developed. AD is a viable alternative for generating those sensitivities. It generates exact derivatives, at a cost which can be lower than finite differencing.

Future Plans: Other AD procedures exist which are now being examined. This includes the ADIFOR computer program developed at Argonne National Laboratory. The first implementation of AD likely will be the HiSAIR/Pathfinder study which integrates aerodynamic, structural and performance optimization of a simple supersonic transport. This integration study relies on calculation of a large number of derivatives of coupling terms between disciplines and therefore is a prime candidate for application of AD.

Figure 78 (a).



Truss Problem	52 bars
Indep./Dep. variables	52/113
Derivative times (sec)	
Finite differences	36
Automatic Differentiation	7

Figure 78 (b).

NEURAL NETS OFFER SIGNIFICANT PAYOFFS IN OPTIMIZATION

James L. Rogers
and
William J. LaMarsh II (Unisys Corporation)

RTOP 505-63-50

Research Objective: Because neural net concepts appear to be attractive for use in structural optimization procedures, this research was undertaken to evaluate the accuracy and efficiency of applying these concepts to approximate a finite-element analysis in structural optimization.

Approach: An optimization procedure was developed wherein a neural network was used to approximate the finite-element analysis that is traditionally coupled to the optimizer. The neural network code was coupled with an optimization code to form a new neural net-based optimization procedure. "Training" of the neural network was accomplished by collecting data obtained by exercising a few cycles of a conventional optimization procedure with a traditional finite-element analysis. Once trained, the neural network replaced the finite-element analysis. For purposes of illustration the new neural net-based method was applied to determine the minimum weight of a cantilever beam loaded at it tip. Internal tresses in the beam were used as constraints. Thicknesses of the beam at five locations along its length were used as design variables. The accuracy and efficiency of the neural network analysis were evaluated by comparing the results with the optimization results obtained with the conventional finite-element analysis.

Accomplishment Description: A sketch of the optimized beam used in the present illustrative example is shown at the top of the figure. The beam was modeled using 640 three-dimensional solid brick finite elements having a total of 3000 degrees-of-freedom. The beam was loaded at the tip and then optimized for minimum weight using both a conventional finite-element/optimizer coupled procedure and the new neural net-based procedure. For the new procedure the neural net was trained using the first five cycles of the application of the conventional optimization procedure. After training, the neural net-based optimization procedure was executed to determine the optimum weight. As can be seen from the graph in the figure, the variation of beam weight with optimization cycle indicates that the neural net-based optimization procedure followed the same path as the conventional optimization procedure. Both procedures essentially converged to the same result after about 14 iterations. As shown by the tabular data in the figure, the total time required using a VAX computer to obtain the net-based solution was only about one-third of the time required by the conventional method. Interestingly, practically all of the net-based time was used in the training phase of the computation.

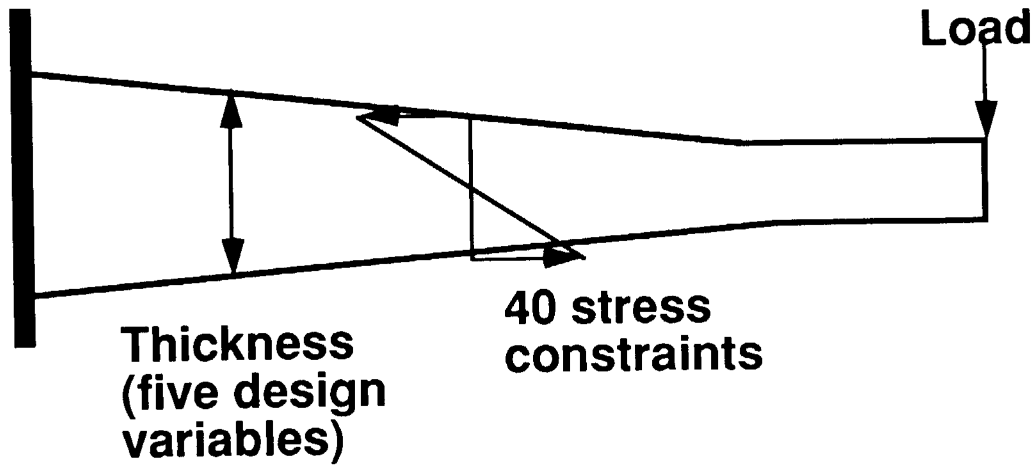
Significance: An investment of time in training neural networks may lead to a significant payoff in time savings in structural optimization analysis. Once trained, the neural network can be used to examine different optimization starting points or different load levels, or to obtain a close approximation to the optimum before returning to the computationally more expensive, conventional optimization procedure for fine tuning of the design if required.

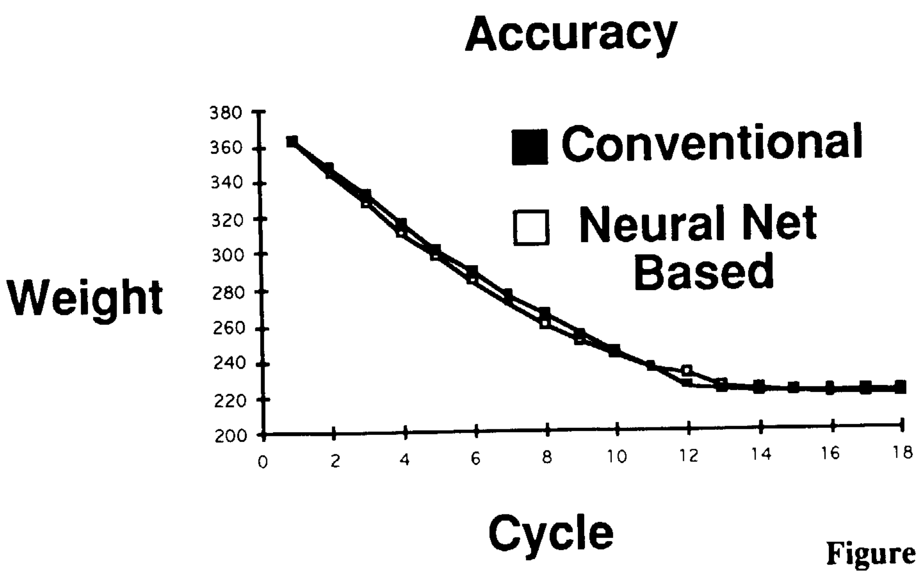
Future Plans: More testing will be done on various models to determine the extent to which one may generalize the above results, which although encouraging, were obtained for a particular case. One broad class of applications to be explored are rotorcraft optimization problems.

Figure 79 (a).

NEURAL NETS OFFER SIGNIFICANT PAYOFFS IN OPTIMIZATION

Optimize Cantilever Beam for Minimum Weight





Efficiency

Time (hours) VAX

	Conventional	Neural Net
Training	0.	10.5
Optimization	32.	1/60

Figure 79 (b).

AERODYNAMIC PERFORMANCE OF ROTOR BLADES COMPUTED USING NEURAL NETWORKS

Joanne L. Walsh, James L. Rogers
and
William J. LaMarsh II (Unisys Corporation)

RTOP 506-63-36

Research Objective: This research is part of a Langley Research Center effort to improve the rotor blade design process. The objective is to accurately approximate the expensive, time-consuming rotor analysis with a fast inexpensive neural network in a rotor blade aerodynamic performance optimization procedure.

Approach: A neural network has been used to approximate the rotor analysis in a rotor blade aerodynamic performance optimization procedure. The optimization procedure minimizes an objective function which is a linear combination of horsepower required for hover, forward flight, and maneuver. The design variables (see fig. 80 (b)) are linear pretwist, taper initiation, taper ratio, and blade root chord. Constraints consist of limits on horsepower required (for hover, forward flight, and maneuver) and requirements on blade stall avoidance, blade trim, and minimum tip chord. The conventional optimization procedure uses the comprehensive helicopter analysis CAMRAD/JA for the forward flight and maneuver flight conditions and the Langley-developed code HOVT for the hover analysis.

Accomplishment Description: Seven neural networks (one for hover, forward flight , and maneuver horsepowers; one for each forward flight and maneuver stall constraints; and one for each forward flight and maneuver trim constraints) were developed and tested to see how well they could match results from the analysis programs CAMRAD/JA and HOVT. Figure 80 (c) compares results for the horsepowers required and analysis times using the rotor analyses and the neural network for two blade test cases. Case 1 is a rectangular blade with -9.0 degrees of pretwist and a root chord of 5.04 in. Case 2 is a blade which is rectangular out to 63 percent radius, tapers linearly to the tip with a taper ratio of 1.28, and has a blade root chord of 4.04 in. For both cases, the neural network analysis is in good agreement with the rotor analyses.

Significance: Results from the *trained* neural networks produced close agreement with those using rotor analyses, but in a fraction of the turnaround time (see fig. 80 (c)). Determining the number of training pairs, neural network setup, and time required to *train* the neural network dictate if continued and extensive use of neural networks are advantageous.

Future Plans: Determine the most efficient neural network configuration (number of hidden layers, number of nodes on the hidden layers, etc.); reduce training time using parallel systems and more robust algorithms; increase the number of design variables as inputs into the neural network; and determine appropriate techniques for selection of training pairs.

Figure 80 (a).

AERODYNAMIC PERFORMANCE OF ROTOR BLADES COMPUTED USING NEURAL NETWORKS

- Objective function = $K_1\,HP_H + K_2HP_{FF} + K_3HP_M$
- Design variables
  - Pretwist (τ_{max})
  - Taper initiation (r/R)
  - Taper ratio (c_r/c_t)
  - Root chord (c_r)

- Constraints
  - Horsepower required
  - Trim
  - Stall
  - Minimum tip chord

Blade model

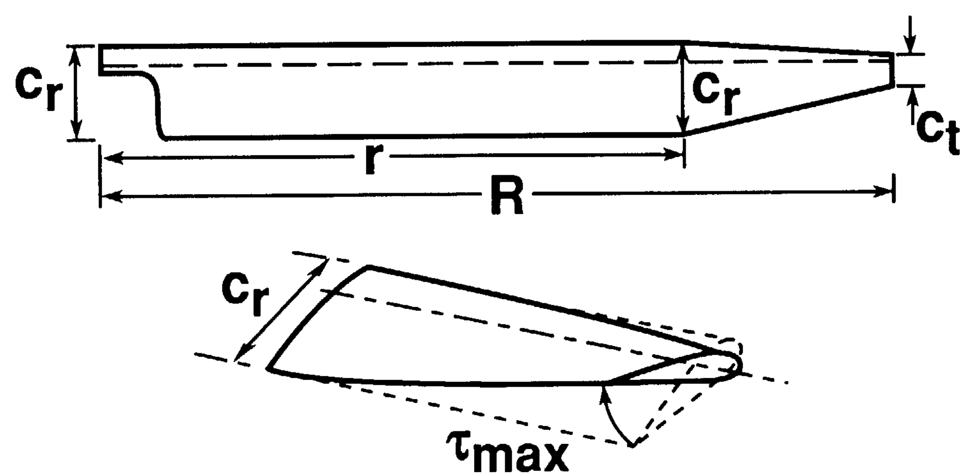


Figure 80 (b).

AERODYNAMIC PERFORMANCE OF ROTOR BLADES COMPUTED USING NEURAL NETWORKS

	Case 1		Case 2	
	Pretwist -9.0 deg Taper initiation - Taper ratio 1.0 Root chord 5.04 in		Pretwist -16.0 deg Taper initiation 0.63 r/R Taper ratio 1.28 Root chord 4.04 in	
	Rotor analysis	Neural network analysis	Rotor analysis	Neural network analysis
Hover hp	15.3	15.3	14.4	14.7
Forward flight hp	13.5	13.2	12.6	12.5
Maneuver hp	12.3	11.6	11.9	11.3
Turnaround time (Sec)	113 Cray 2	1.5 Sparc IPX	89 Cray 2	1.7 Sparc IPX

Figure 80 (c).

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APPLICATION OF A NEURAL NETWORK AS A POTENTIAL AID IN PREDICTING NTF PUMP FAILURE

James L. Rogers (Interdisciplinary Research Office)
William J. LaMarsh II (UNISYS)
Jeffrey S. Hill (High-Reynolds-Number Aerodynamic Branch)
David E. Bradley (New Horizons Program)
RTOP 505-63-50

<u>Research Objective</u> - If one of the liquid nitrogen pumps at the national Transonic Facility (NTF) fails, the result is significant downtime for the tunnel and substantial repair costs for the pump. Changes in the amplitudes at certain critical frequencies could be used in detecting a pump rotating component problem, and allow the pump to be stopped before a failure occurs. Data containing these amplitudes are available from frequency scans generated by accelerometers attached to the pumps, but no techniques have been available to use this data in predicting pump failure. The objective of this project is to develop a new tool which couples neural network techniques with the accelerometer data as an aid in predicting pump failure.

<u>Approach</u> - NTF operational experience has shown that responses in the neighborhood of five frequencies are the most critical in detecting a pump problem. These frequencies are (1) the fundamental train frequency (FTF), (2) the ball pass frequency of the inner race (BPFI), (3) the ball pass frequency of the outer race (BPFO), (4) the ball spin frequency (BSF), and (5) the pump frequency (PF). There is an unknown relationship between the pump frequency and the other four. A neural network can be applied to determine this relationship. The neural network has four input nodes (representing the amplitudes at the first four frequencies) and one output node (the amplitude at the pump frequency). The weights connecting the input nodes to the output node represent the relationship. Training the neural network determines the values of these weights. Once the neural network has been trained, different combinations of the amplitudes at the first four frequencies can be input to the neural network to compute amplitudes at the pump frequency. These combinations can then be displayed on a contour plot to indicate potential problems areas.

<u>Accomplishment Description</u> - Six training pairs were selected from frequency scans to train the neural network. A training pair is a known set of four inputs (amplitudes at FTF, BPFI, BPFO, and BSF) and one output (amplitude at PF). The initial weights of the neural network are randomly generated. The known inputs and the weights are used to compute an output. The computed output is then compared to the known output and an RMS difference is computed. This difference is used to modify the weights. The process is continued until an RMS difference of .001 is obtained. Once trained, 6561 (an 81x81 matrix) different combinations of the input amplitudes are propagated through the neural network to compute the amplitudes at the pump frequencies. These values are used to create the contour plot shown in the figure. The x-axis contains ranges of amplitudes at FTF and BPFI. The y-axis contains ranges of amplitudes at BPFO and BSF. The contour plot consists of an 81x81 matrix of boxes where each box represents a unique combination of amplitudes at the four input frequencies, with the color of the box representing the computed output value of the amplitude at PF. White indicates everything is normal, gray indicates a warning zone, and black indicates a danger zone and the pump should be stopped.

<u>Significance</u> - The tunnel operator could use this contour plot as an aid in predicting pump failure by coupling it with a monitoring system. As the tunnel operator monitors the changes while the tunnel is in operation, any changes would alert the operator to a potential problem when the monitoring indicates a drift towards a gray zone. The pump could then be stopped before it enters into a black zone and damage occurs. If the pump is stopped before damage occurs then the pump could probably be repaired in-house which would significantly reduce costs and reduce downtime from months to weeks.

<u>Future Plans</u> - To make this system operational, hardware would have to be purchased to set up the monitoring and display system. In addition, numerous training pairs would have to transcribed from the frequency scans to train the neural network to sufficient accuracy.

Figure 81 (a).

APPLICATION OF A NEURAL NETWORK AS A POTENTIAL AID IN PREDICTING NTF PUMP FAILURE

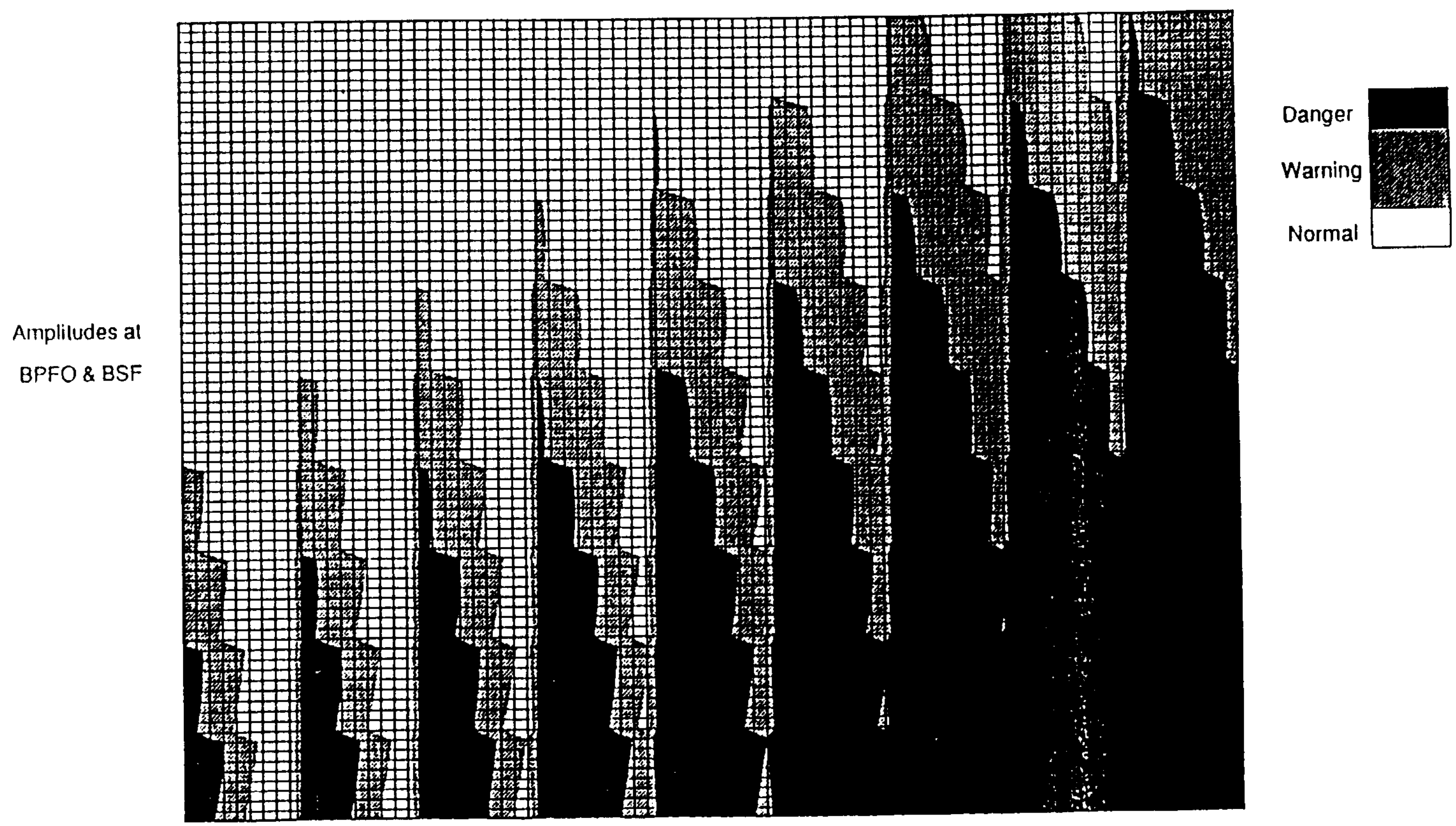


Figure 81 (b).

F.Y. 1993 PLANS

The following pages include some research areas which will be pursued by the Structural Dynamics Division organizations in fiscal year 1993.

CONFIGURATION AEROELASTICITY
F.Y. 1993 PLANS

- Complete tests of a Gulfstream G-V wing flutter model in the TDT
- Complete a flutter and benchmark aerodynamic measurements study of a Cessna Citation X wing model in the TDT
- Complete transport model tests in the TDT to determine limit cycle oscillation flutter
- Complete TDT test to determine effects of free play on control surface flutter
- Complete tests of a full span NASP model for studying fuselage flexibility effects on flutter in the TDT
- Complete tests of a NASP wing model for studying static divergence in the Supersonic Unitary Plan Wind-Tunnel
- Complete ground tests and wind-tunnel open-loop tests of the benchmark active controls model in the TDT
- Complete vibration loads and performance test of the BERP-like blades and blades with tip controls in the TDT
- Complete engineering study to determine candidate replacement heavy gases for the TDT

Figure 82

AIRCRAFT AEROELASTICITY

Stanley R. Cole
Configuration Aeroelasticity Branch

RTOP 505-63-50 and RTOP 763-23-45

Research Objective: The objectives in the aircraft aeroelasticity technical area are to determine and solve the aeroelastic problems of current designs, and to develop the understanding and prediction capabilities needed to apply new aerodynamic and structural concepts to future flight vehicles.

Approach: The types of research included in the aeroelasticity area are illustrated in the accompanying figure. This research is a combination of experimental and complementary analytical studies. The experimental work focuses on the use of the Langley Transonic Dynamics Tunnel (TDT) which is specifically designed to meet the unique needs of aeroelastic testing. On occasion flight research programs are undertaken when it is necessary to simulate important parameters that cannot be accurately accounted for in ground-based facilities. Often research is a cooperative effort with other government agencies and/or industry.

Status/Plans: Work for the coming year includes several activities, some of which are described as follows. Analytical and experimental investigations will continue to provide flutter data to support development of advanced subsonic transports, advanced fighter configurations, and the National Aerospace Plane (NASP). During the early part of 1993, there will be two joint studies conducted in the TDT concerning small transport-class aircraft, one with the Cessna Aircraft Company and one with the Gulfstream Aerospace Corporation. The first study will be an experimental determination of the flutter charcteristics of the new Cessna Citation X configuration. A secondary purpose of this study will be to obtain benchmark pressure data for use in validating advanced aerodynamic and aeroelastic analysis codes which are used to predict the stability characteristics of this class of wings. The second study involves the determination of the flutter characteristics of the Gulfstream V advanced subsonic transport wing. There are three cooperative studies planned during the upcoming year for advanced fighter aircraft configurations. The first is a joint effort with the General Dynamics Corporation to examine the effects of free-play on the flutter of various fighter lifting surfaces. This test is scheduled to occur during March of 1993. The second research effort is primarily a flutter clearance test for the planned F/A-18 E/F. The third fighter model will also be a flutter clearance study for the F-22 vehicle including various store configurations. Further study efforts will also continue in 1993 for the NASP. A full span model test to study fuselage flexibility effects on flutter is scheduled for December, 1992 in the TDT. Simple wing models tests currently are scheduled for January, 1993 in the Langley Hypersonic Helium Tunnel. A joint effort between NASA Langley and Wright Laboratory will be to test a NASP wing surface model in the TDT and a panel flutter model in the Langley Supersonic Unitary Plan Wind Tunnel. There will also be a design, fabrication, and test effort for an aeroelastic model of a NASP engine for testing in the TDT during 1993.

Figure 83 (a).

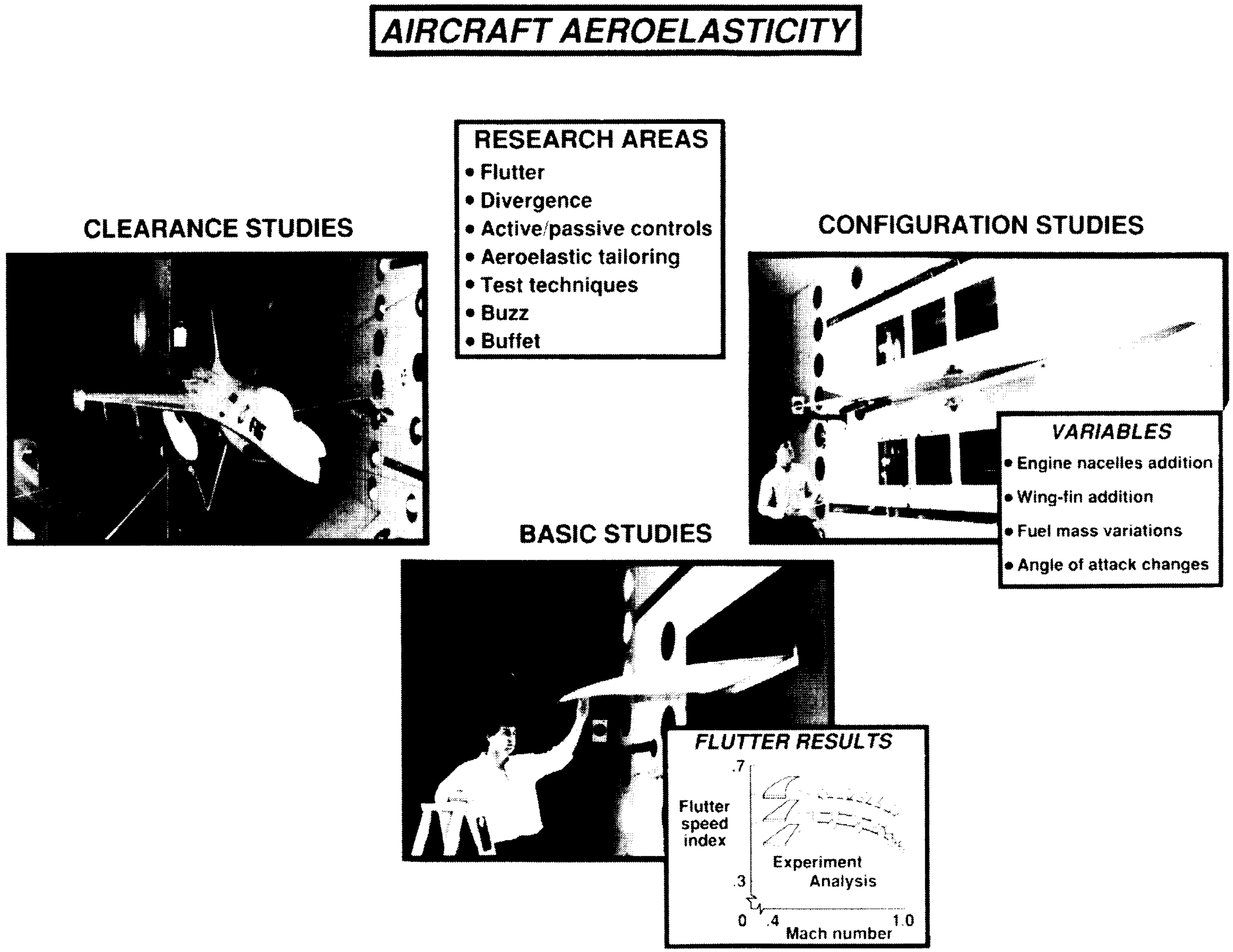


Figure 83 (b).

C-3

BENCHMARK MODELS

Michael H. Durham
Configuration Aeroelasticity Branch

RTOP 505-63-50

Research Objective: The objectives of the Benchmark Models Program are to provide test data for evaluating new capabilities of computational aeroelasticity codes, increase physical understanding of unsteady flow phenomena, and provide test data for developing empirical design methods where computational methods are not available.

Approach: The Benchmark Models Program is a Structural Dynamics Division research effort involving the Configuration Aeroelasticity Branch, the Unsteady Aerodynamics Branch, and the Aeroservoelasticity Branch. Critical aeroelastic conditions needing test data for evaluation involve dynamic, mixed-flow phenomena at off-design flight conditions near envelope boundaries. The primary approach is to test instrumented well-defined dynamic models up to unstable flight conditions while recording unsteady pressures, dynamic loads, and qualitative flow visualizations. Transonic aeroelastic instabilities are of a particular interest due to their complicated flow conditions involving shocks and separated flows.

Status/Plans: The design and fabrication of four instrumented rigid rectangular wing models has been completed. These rigid models are to be flutter tested on a flexible mount system with pitch and plunge degrees of freedom providing a well-defined dynamic system. Two models in this series, the first having a NACA0012 and the second with a SC(2)-0414 airfoil, have successfully completed wind-tunnel tests with data reduction and formal documentation underway. A third model in this series was fabricated with a 64A010 airfoil. All three models will be tested to flutter while recording two chords of unsteady pressure instrumentation totaling 80 transducers. Another rigid model has been fabricated for active controls testing. This model is similar to the NACA0012 but with the addition of an active trailing edge control surface plus upper and lower surface spoilers. The purpose of this model is to quantitatively measure overall unsteady pressure effects and control surface effectiveness during flutter suppression. This model will also provide a simple well-defined controls testbed to explore new control methods such as multi-rate/multi-function control and flutter suppression with actively controlled spoilers. A new Benchmark project is underway on a high-speed transport configuration. Two models are being designed each with 175 dynamic pressure transducers. The first is a rigid model which will be tested both cantilevered from a balance on the wall and attached to a flexible pitch and plunge apparatus. The second model is a flexible aeroelastic model that will be tested to flutter while recording unsteady pressures as well as model static and dynamic deflections.

Figure 84 (a).

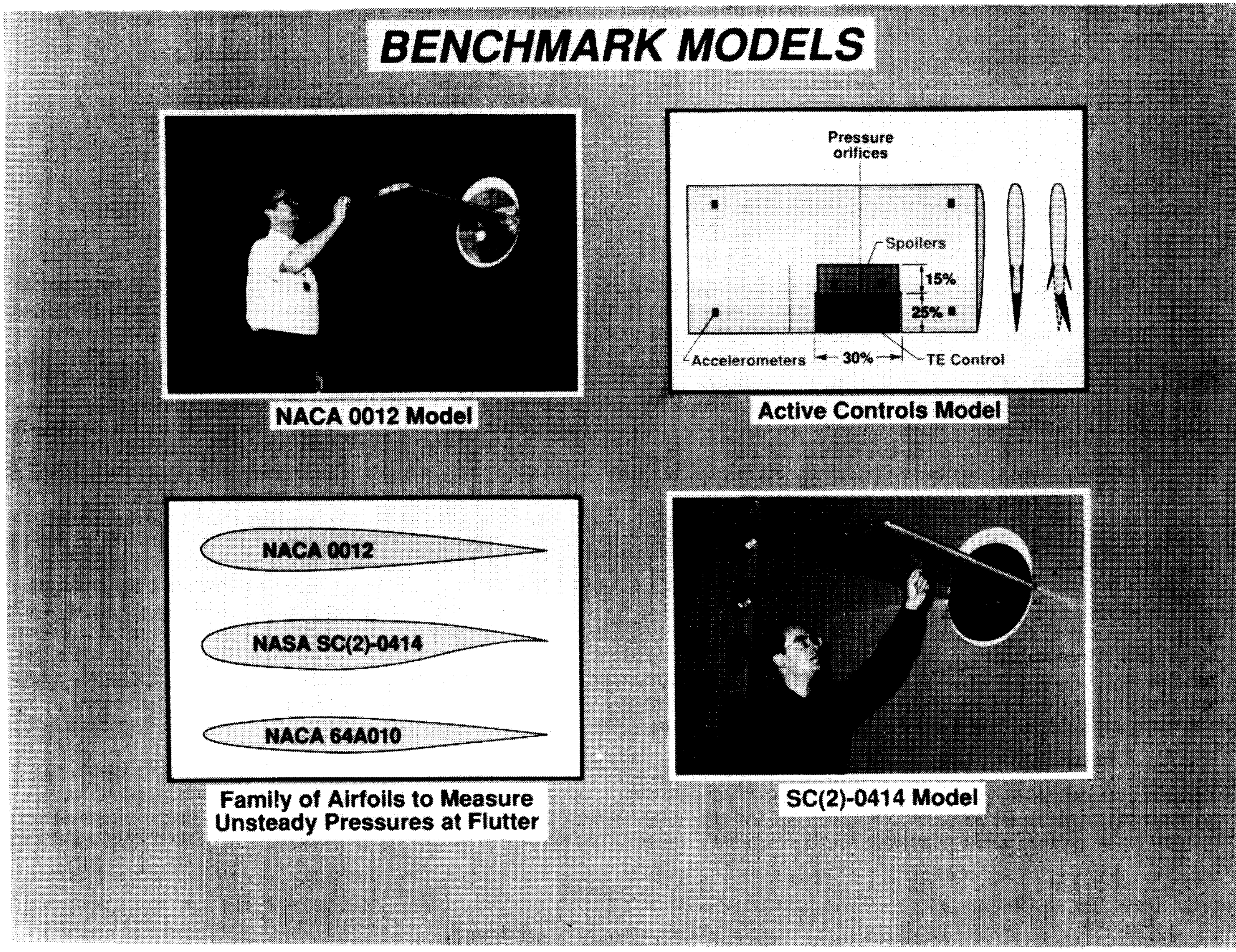

BENCHMARK MODELS
NACA 0012 Model
Pressure orifices
Spoilers
15%
25%
Accelerometers
30%
TE Control
Active Controls Model
NACA 0012
NASA SC(2)-0414
NACA 64A010
Family of Airfoils to Measure Unsteady Pressures at Flutter
SC(2)-0414 Model

Figure 84 (b).

ROTORCRAFT AEROELASTICITY

William T. Yeager, Jr.
Configuration Aeroelasticity Branch

505-63-36

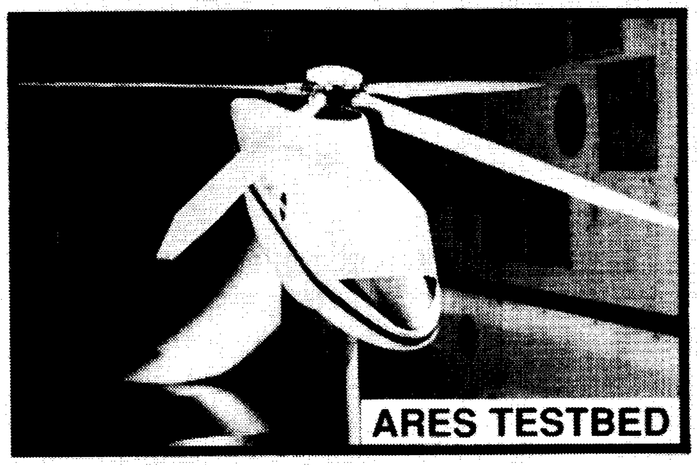
Research Objective: The objectives in this technical area are to (1) conduct research in the aeroelastic, aerodynamic, and dynamic characteristics of rotors; (2) support design of advanced performance rotorcraft and the upgrade of existing rotorcraft in the areas of loads, vibration, aeroelastic stability, and rotor performance; and (3) develop the experimental and analytical techniques necessary to extend wind tunnel and laboratory capabilities to future research requirements and opportunities.

Approach: This research is a joint effort of SDyD and the U.S. Army Vehicle Structures Directorate which is collocated at Langley. The in-house civil research is supplemented by industry contracts and university grants. The Aeroelastic Rotor Experimental System (ARES) testbed, shown in the accompanying figure, is key to the conduct of experimental studies conducted in the TDT and the Helicopter Hover Facility. This testbed, which has drive mechanisms, a strain-gage force and moment balance, and other equipment housed in a generic fuselage shape, provides a means for studying a variety of rotor systems in forward flight in the TDT and in hover in the HHF. An advanced version of the ARES (ARES II) is being developed which makes it possible to better model the coupling of the rotor and the body. The ARES II design mounts the metric section of the ARES testbed on a platform supported by six computer controlled hydraulic actuators which are used to obtain the desired body roll, pitch, yaw , side , normal, and axial motion. A sample of fixed-system vibratory loads obtained using the ARES is shown in the accompanying figure. Analytical studies include the use of existing analyses such as NASTRAN, CAMRAD, DYSCO, UMARC, PASTA and 2GCHAS.

Status/Plans: Initial testing of an in-house developed close-loop analog controller for ARES II has been completed. Stability testing of a hingeless rotor was conducted in the HHF using the "soft mount" version of the ARES (ARES 1.5). Testing in the TDT of a BERP-type rotor and a Phase I HIMARCS rotor was completed using an in-house developed automatic control system for the ARES testbed. Fabrication of a rotating balance for the ARES testbeds was completed. Plans call for use of the rotating balance following static and dynamic calibrations. Testing of a Parametric Bearingless Hub (PBH) in the HHF will begin during C.Y. 1993. Fabrication was begun on a set of model optimized rotor blades as part of the Langley rotorcraft optimization/validation effort. A preliminary design study was started on a set of model generic rotor blades to be used to acquire data for code validation and to study rotor blade passive tailoring to reduce fixed-system vibratory loads. Tests will be conducted in C.Y. 1993 in the TDT to complete an aeromechanical stability data base for hingeless rotors and to support the Langley rotorcraft optimization/ validation program.

Figure 85 (a).

ROTORCRAFT AEROELASTICITY



RESEARCH AREAS

*Vibration reduction

*Aeromechanical stability

*Rotor performance

COMPREHENSIVE ANALYSES

*2GCHAS

*CAMRAD

*NASTRAN

*DYSCO

*UMARC

*PASTA

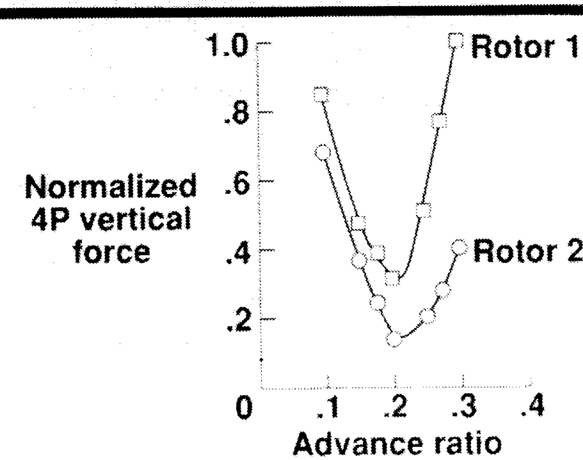


Figure 85 (b).

UNSTEADY AERODYNAMICS
F. Y. 1993 PLANS

- CAP-TSD code application and support

    - Incorporate and validate inverse boundary layer method
    - Validate flexible fuselage and flexible, swept vertical tail capabilities
    - Continue in-house and industry and university cooperative applications to verify the code's range of accuracy
    - Continue to provide programming support

- Development and validation of Euler and Navier-Stokes capabilities for aerodynamic and aeroelastic analysis

    - Structured grid flow solvers
    - Unstructured grid flow solvers
    - Gridless flow solvers
    - Viscous-dominated flows and vortex-dominated flows
    - Turbulence modeling
    - Grid generation methodology

- Support of Benchmark Models Program

    - Continue support of wind-tunnel tests and pretest and post-test data analysis
    - Complete design of rigid high-speed civil transport benchmark model

Figure 86

AEROSERVOELASTICITY
F. Y. 1993 PLANS

- Complete first wind-tunnel test of the BACT model
- *Establish disciplinary data interfaces in support of HiSAIR design studies
- *Definition of aerodynamic Volterra integrals for nonlinear control interactions planned
- Develop simulation laboratory to assess ASE in near-real time
- Apply MFT to aircraft with Nonlinear Control System
- Develop aeroelastic analysis procedure for tiltrotor aircraft
- *Large pretwist effects in extension-twist-coupled composite blade spars
- *The piezoelectric aeroelastic response tailoring investigation
- *Experimental validation of panel flutter suppression using shape memory actuators
- *Neural-network-based systems studied for adaptive flutter suppression
- *Use of active materials as internal structural actuators to reduce transonic drag

*Figures and Text Included

Figure 87

ESTABLISH DISCIPLINARY DATA INTERFACES IN SUPPORT OF HISAIR DESIGN STUDIES

Thomas A. Zeiler
Lockheed Engineering and Sciences Company

RTOP 505-63-50

Objective: The thrust of the High Speed Airframe Integration Research (HiSAIR) project is to develop methodologies for incorporating analysis results from multiple disciplines as early in the design process as possible. In support of HiSAIR, the Aeroservoelasticity Branch (ASEB) is to provide assessments of the aeroelastic characteristics of the vehicle in question and sensitivities, with respect to design variables, of these characteristics suitable for use as constraints and gradients in a design optimization. The objective of this activity is to establish the data interfaces between the aeroelastic analyses and both the sources of structural dynamic data used in aeroelastic modeling and the groups in need of the aeroelastic constraint data.

Approach: The Aeroelastic Vehicle Analysis (AVA) system of computer codes is used for the aeroelastic analyses and sensitivity calculations. One set of data interfaces is with the Aircraft Structures Branch in the Structural Mechanics Division (ASB/SMD). ASB produces the detailed finite element model of the vehicle and is in need of flutter and divergence information to produce an adequately sized initial structure. The other set of data interfaces is with the Interdisciplinary Research Office in the Structural Dynamics Division (IRO/SDyD). IRO produces the simplified plate model of the structure, in coordination with the finite element model produced by ASB. The plate model is used in the main design iterations because of its relative simplicity. These two models are depicted within the top box in the figure; the operations performed by the AVA system of computer codes are depicted in the bottom box; and the interfaces are depicted by the arrows connecting the boxes. Available computer platforms are used to transmit the structural dynamic data (modes, mass, stiffness, and sensitivities of the mass and stiffness) and the aeroelastic constraint data in necessary formats (e.g. flutter speeds, as depicted in the figure).

Status/Plans: To date, a full two-way exchange of data between ASEB and ASB, and a resizing iteration cycle has been accomplished using a finite element model of the earlier HiSAIR Mach 3.0 vehicle wing and a single flutter point. Further plans are to complete the resizing iterations until the flutter constraint is satisfied. This will be followed by another resizing exercise duplicating the process with multiple aeroelastic constraints. The data exchange with IRO is, as yet, only one-way with modes, mass, stiffness, and sensitivities of mass and stiffness having been transmitted to ASEB. Aeroelastic analyses and sensitivities have been successfully computed using these data. Further plans are to complete the two-way data exchange, and, as with ASB, use the data exchange in a structural resizing exercise that includes aeroelastic constraints.

Figure 88 (a).

ESTABLISH DISCIPLINARY DATA INTERFACES IN SUPPORT OF HiSAIR DESIGN STUDIES

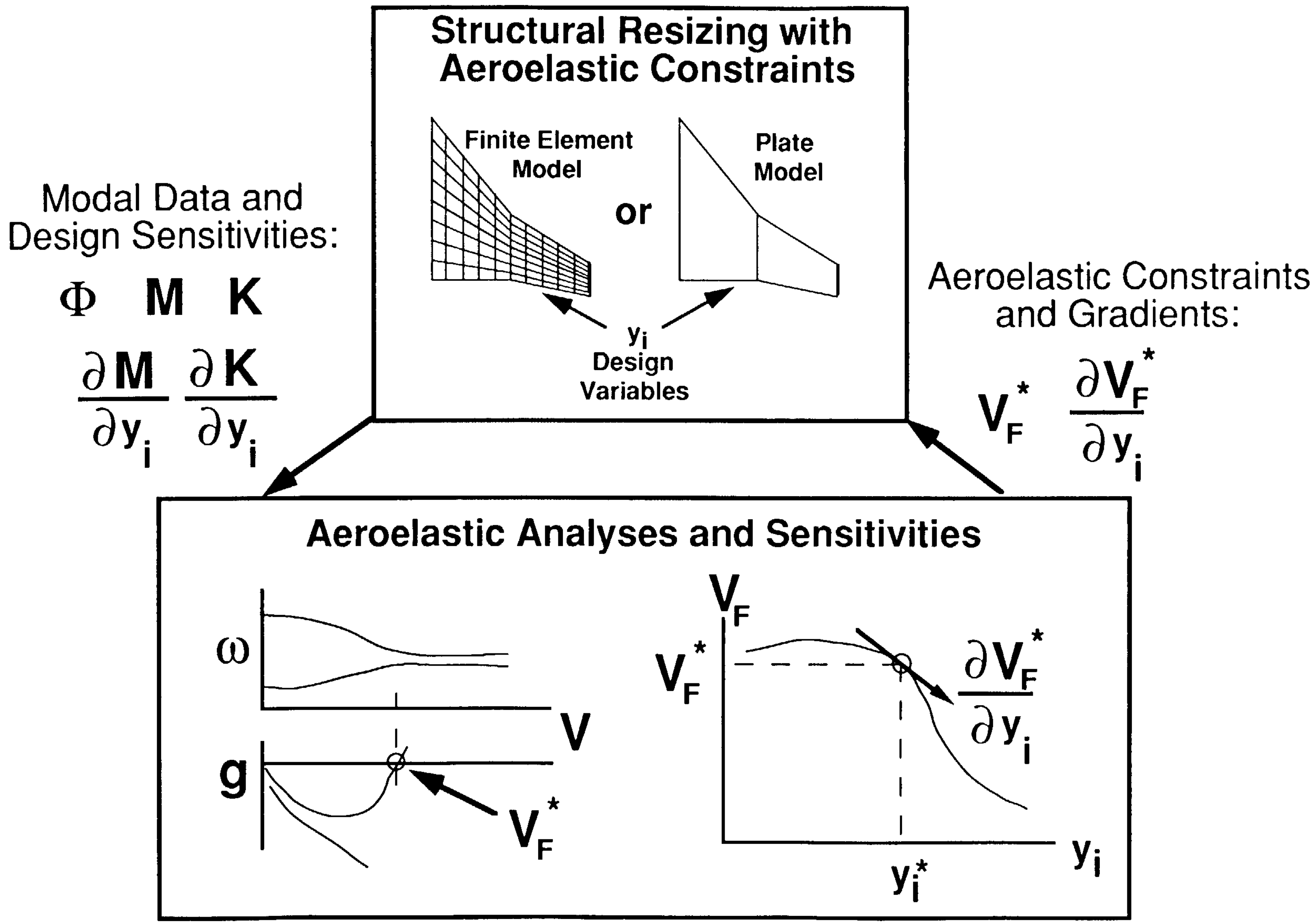


Figure 88 (b).

DEFINITION OF AERODYNAMIC VOLTERRA INTEGRALS FOR NONLINEAR CONTROL INTERACTIONS PLANNED

Walter A. Silva
Unsteady Aerodynamics Branch

Carol D. Wieseman and Vivek Mukhopadhyay
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objectives: The objectives of this research are: 1) to continue development of a methodology for using the Volterra-Wiener theory of nonlinear systems for defining nonlinear unsteady aerodynamic responses; 2) to integrate this methodology into modern aeroservoelastic analysis and design techniques in order to design control laws that can account for aerodynamic/aeroelastic nonlinearities; and 3) to evaluate the control law design techniques and the entire methodology by incorporating control laws within the CFD analysis and performing closed-loop time simulation.

Approach: This research entails the integration of three key technical disciplines (see figure). The first discipline involves the use of computational fluid dynamics (CFD) as shown in the upper left circle. A CFD aeroelasticity code will be used to generate the nonlinear aerodynamic/aeroelastic responses from which Volterra kernels are obtained. These kernels, which are functions of time, are then used for the realization of system matrices that define the nonlinear response of the aeroelastic system to arbitrary inputs, shown in the upper right circle. This system realization (or identification) is the second key discipline. Once a system of equations has been determined, the resultant nonlinear plant can be used for designing linear or nonlinear control systems that can address aerodynamic/aeroelastic nonlinearities. This is performed by the third key discipline shown at the bottom of the figure. Finally the designed control law will be incorporated into the CFD code to simulate the effectiveness of the control law design and the entire methodology.

Status/Plans: The CAP-TSD (Computational Aeroelasticity Program-Transonic Small Disturbance) code is presently being used with other software to obtain the nonlinear Volterra kernels. To gain experience in applying the procedures, a rigid rectangular wing with pitch and plunge degrees of freedom is being analyzed. The results of these calculations will be provided in a paper being considered for presentation at AIAA 34th Structures, Structural Dynamics, and Materials Conference to be held in April of 1993. In terms of future work, the system realization/identification process will be performed using the Eigensystem Realization Algorithm (ERA) routines developed by the Spacecraft Dynamics Branch. Modern control theory, in addition to bilinear optimal control theory, will be applied when designing control systems.

Figure 89 (a).

DEFINITION OF AERODYNAMIC VOLTERRA INTEGRALS FOR NONLINEAR CONTROL INTERACTIONS PLANNED

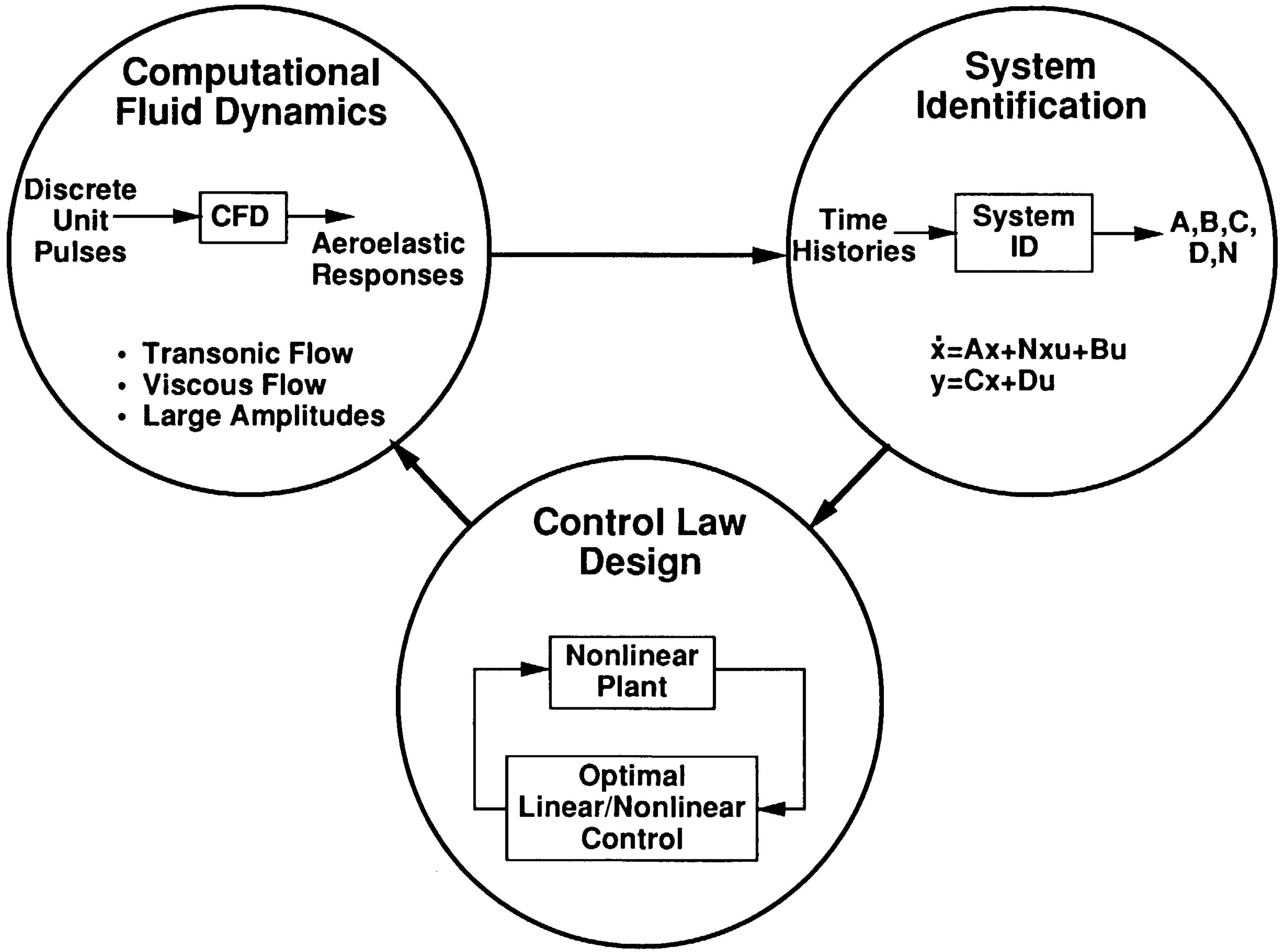


Figure 89 (b).

LARGE PRE-TWIST EFFECTS IN EXTENSION-TWIST-COUPLED COMPOSITE BLADE SPARS

Renee C. Lake and Mark W. Nixon
Aeroservoelasticity Branch

RTOP 505-63-36

Research Objective: Composite materials technology offers considerable advantages in the design of advanced rotor blades with respect to strength and weight criteria, in addition to providing a means of efficiently controlling static and dynamic response through the implementation of elastic tailoring. Extension-twist elastic coupling, which exhibits coupling among the extensional and torsional stiffnesses of a structure due to an unbalanced ply layup, is being studied as a viable means of improving the dynamic and aerodynamic characteristics of composite rotor blades. In-house research efforts have recently shown that this type of design technology may be advantageously applied to the design of tiltrotor blades, which are more highly twisted than conventional helicopter rotor blades, and are designed to operate in both helicopter and airplane modes of flight. Tiltrotor aircraft typically vary rotor speed by about 20 percent between the two flight modes, which induces a rather substantial change in the centrifugal force. A design that allows blade twist to change passively as a function of this difference in centrifugal force would thus lead to increased performance for tiltrotor aircraft. However, the elastic twist of the blade may also be influenced by the incorporation of pre-twist into the blade geometry, which can enhance or detract from the overall twist obtained, depending upon the location of the initial twist axis as well as the magnitude of pre-twist. Therefore, the objective of this research is to investigate the effects of large pre-twist angles in the design of extension-twist-coupled tiltrotor blades.

Approach: This in-house research study is being conducted using the following approach: (1) design, fabricate and test extension-twist-coupled tubular spars with large built-in twist angles; (2) validate analytical dynamics methods for pre-twisted blade structures; (3) design, fabricate and test aeroelastically-tailored composite tiltrotor blades.

Status/Plans: The highly twisted extension-twist-coupled tubular spars have been fabricated and are currently being readied for static testing. Analysis has been used to predict the magnitude of elastic twist associated with the coupling effect, the pretwist effect, and the combined effects. Various composite layups have been used in the specimens so that the coupling and pretwist effects can be isolated in the experiment and then correlated with the analytical predictions. Dynamic free-free vibration tests will also be conducted on these specimens. Results of this study will be helpful in the design of a set of highly twisted scaled model rotor blades that incorporate the extension-twist concept.

Figure 90 (a).

LARGE PRETWIST EFFECTS IN EXTENSION-TWIST-COUPLED COMPOSITE BLADE SPARS

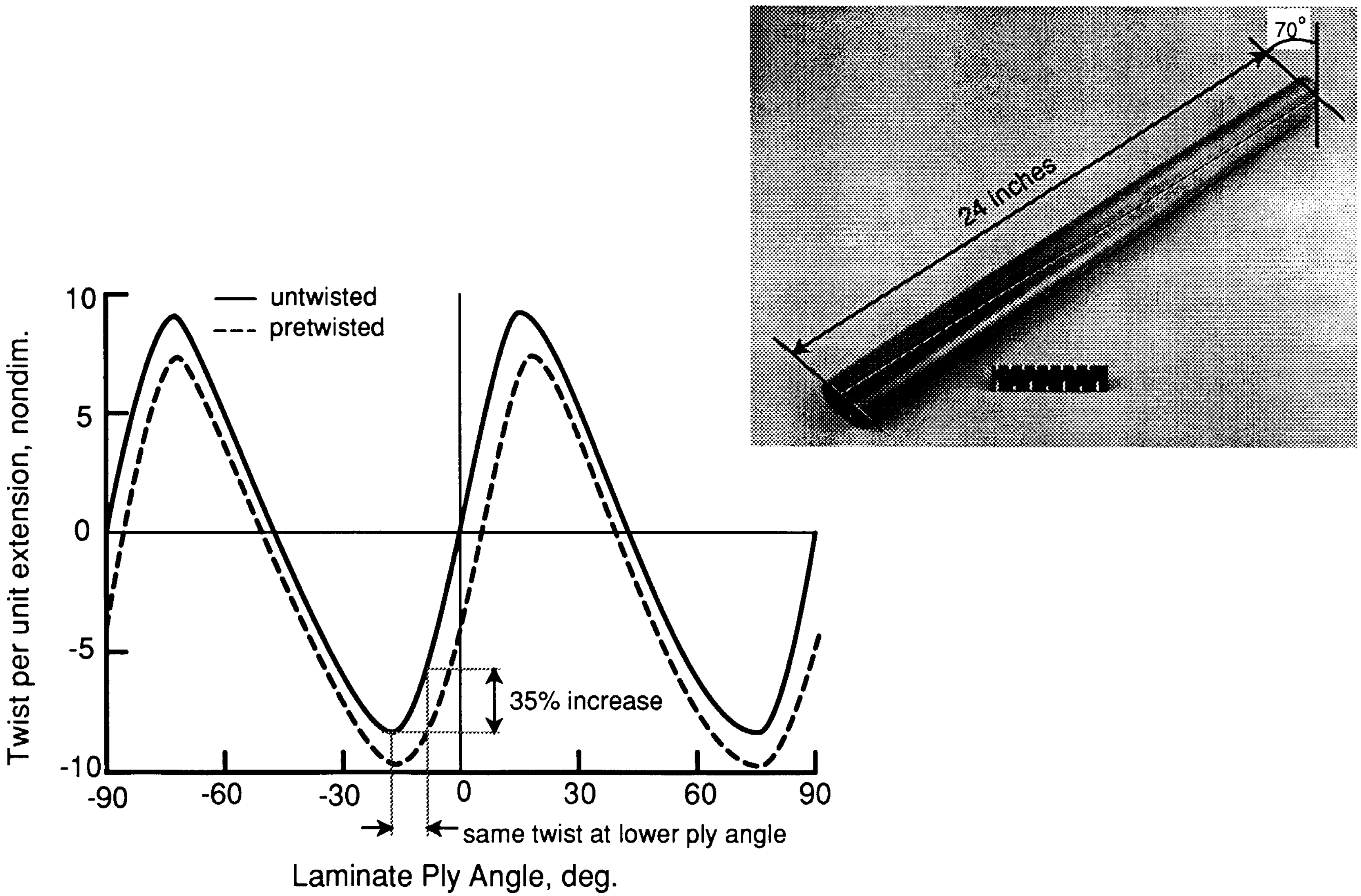


Figure 90 (b).

THE PIEZOELECTRIC AEROELASTIC RESPONSE TAILORING INVESTIGATION

Jennifer Heeg
Aeroservoelasticity Branch

Edward Crawley and Charrissa Lin
Massachusetts Institute of Technology

RTOP 505-63-50

Research Objective: The piezoelectric aeroelastic response tailoring investigation (PARTI) aims at demonstrating the ability of strain-actuation to suppress wing flutter and to tailor wing aeroelastic response. It is also the objective of this research to evaluate the relative control effectiveness of structural and aerodynamic actuators. Additional goals for the investigation include development of detailed analysis and experimental techniques for treatment of adaptive materials, and enhancement of support technologies.

Approach: The approach is to assemble a multidisciplinary team of engineers who will design, build, and test an aeroelastic actively-controlled wind-tunnel model. Three branches within the Structural Dynamics Division (ASEB, CAB, and IRO) and the Massachusetts Institute of Technology are partners in this cooperative effort and comprise the PARTI team. The PARTI model is a cantilevered composite wing, representative of the transport class, with a sandwich-construction structural box enclosed by an aerodynamic shell. The upper left corner of the figure contains a plan view of the model. Piezoelectric plate actuators cover the inboard two-thirds of the structural box. An aerodynamic trailing edge control surface is located between the 60- and 80-percent span stations. As indicated at the bottom of the figure, graphite-epoxy plates surround the aluminum honeycomb core to form the structural box. Active aeroelastic control schemes will use the piezoelectric actuators and the aerodynamic control surface singly and in combination. The plot on the right side of the figure illustrates the two active controls tasks: (1) increase the flutter dynamic pressure; and (2) tailor the subcritical aeroelastic response.

Status/Plans: The design and analysis phases of the project are nearly complete. The culmination of the design phase will be a critical design review in November 1992, followed by wind-tunnel model fabrication. The PARTI team will design control laws and perform additional analyses of the final model design, leading to ground vibration and zero airspeed controller testing, to be conducted during the fall of 1993. The wind-tunnel test of the open-loop system and functionality checks of the control hardware and software are scheduled for December 1993 and wind-tunnel test of the closed-loop system are scheduled for 1994.

Figure 91 (a).

PIEZOELECTRIC AEROELASTIC RESPONSE TAILORING INVESTIGATION

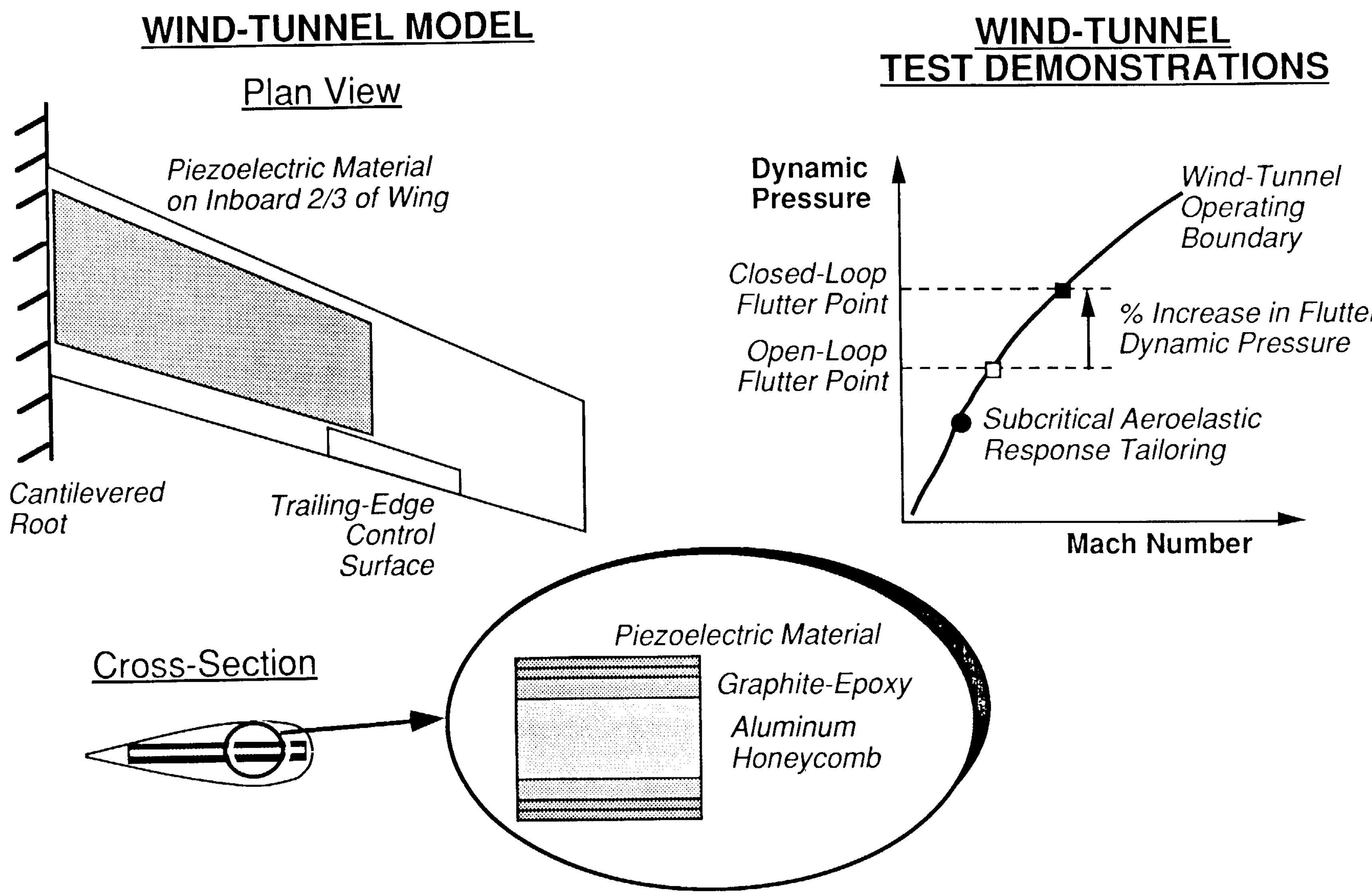


Figure 91 (b).

EXPERIMENTAL VALIDATION OF PANEL FLUTTER SUPPRESSION USING SHAPE MEMORY ACTUATORS

Anna Maria Rivas and Robert C. Scott
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: The objectives of this research are to experimentally validate the use of shape memory alloys (SMA) for passively controlling panel flutter and to develop the analytical methods to predict the behavior of panels constituted with shape memory alloys.

Approach: Panel flutter is largely a supersonic phenomenon that is aggravated by aerodynamic heating. The expansion of aircraft materials during heating results in the development of in-plane compressive stress (or negative differential stiffness) that lowers the flutter dynamic pressure, as shown in the plot in the upper left corner of the figure. By contrast, the plot also shows that if a means were found to create a net in-plane tensile stress, the flutter dynamic pressure would increase. Such a means is available: the application to the panel of a material (SMA) that contracts when heated. The tendency of the applied material to contract creates net in-plane tensile stress in the panel, thereby increasing the flutter speed. Previous in-house and grant work supported by ASEB has demonstrated the potential benefits of this concept. The present investigation will be conducted in the three phases shown in the figure. Feasibility studies will be conducted in phases one and two. These studies will include analyses and tests of beam and plate models constituted with Nitinol, a shape memory alloy material, comprised of Nickel and Titanium, that will function as an actuator. Ground vibration tests of heated and unheated test articles will be conducted and will establish the effectiveness of the SMA for increasing test article stiffness. Phase three will demonstrate panel flutter suppression in the wind tunnel.

Status/Plans: To date, NASTRAN finite element models of beams have been developed and validated with hand calculations. These models have also been enhanced to include the SMA temperature-dependence effects. In addition, the clamping device to be used in the phase-one tests has been designed and fabricated. Phases one and two are expected to be completed by December 1992 and March 1993 respectively. Phase three is presently scheduled to occur in January 1994.

Figure 92 (a).

EXPERIMENTAL VALIDATION OF PANEL FLUTTER SUPPRESSION USING SHAPE MEMORY ACTUATORS

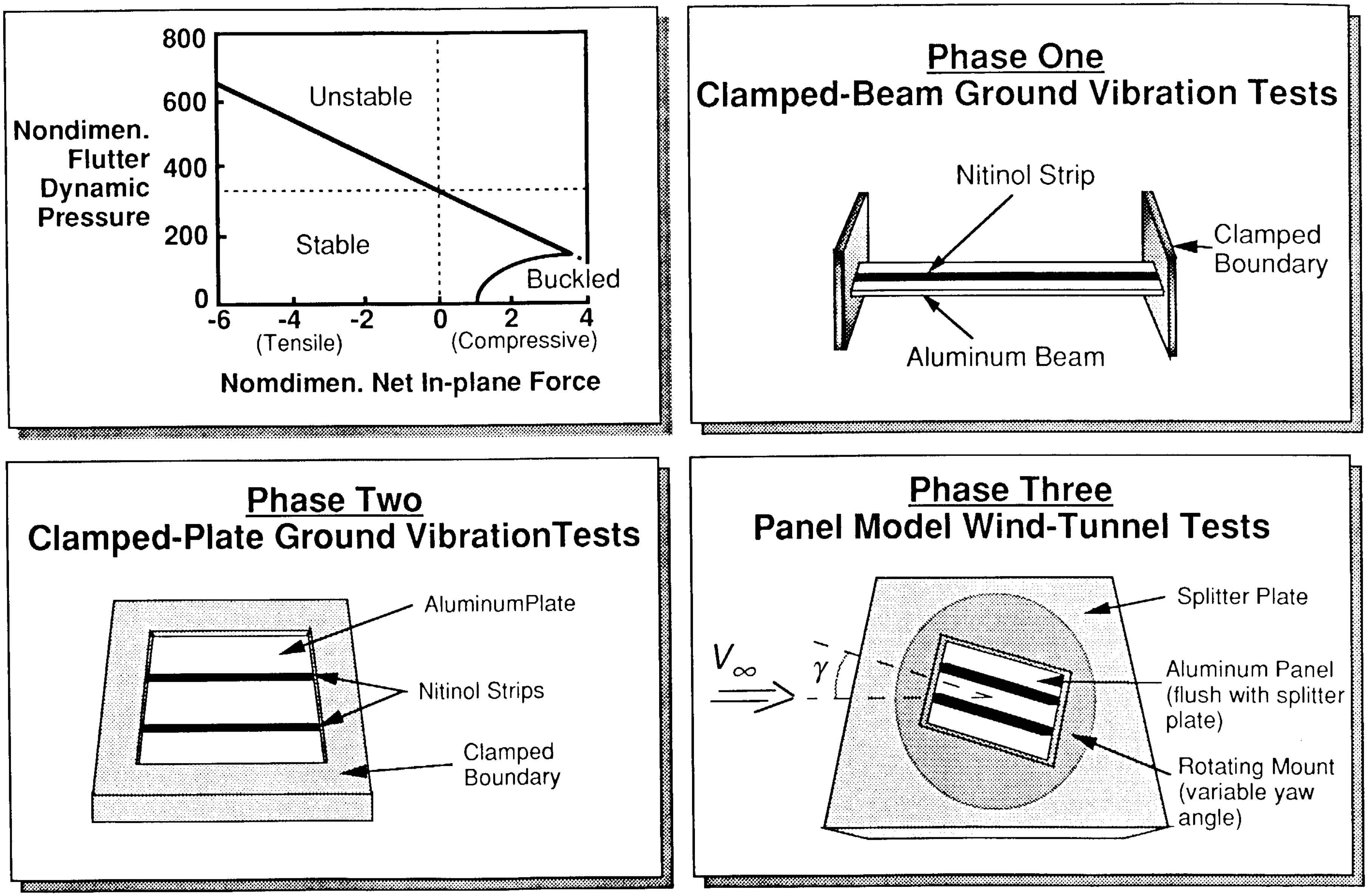


Figure 92 (b)

NEURAL-NETWORK-BASED SYSTEMS STUDIED FOR ADAPTIVE FLUTTER SUPPRESSION

Robert C. Scott and Sherwood Hoadley
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: The objective of this activity is to develop and demonstrate an adaptive neural-network-based flutter suppression system for highly distributed actuation mechanisms.

Approach: The approach is to perform analytical studies to prove the feasibility, and then, to conduct wind-tunnel experiments to verify the concept. Adaptive control laws can adapt to time-varying changes in the plant as well as to sensor and actuator failures. A neural-network-based system is an attractive mechanism for providing the adaptive process. An adaptive control law, coupled with many sensors and actuators, could improve flutter suppression system reliability. For the last three years ASEB has conducted analytical and experimental investigations that have explored the use of "smart" materials for suppressing flutter. One type of "smart" material is the piezoelectric actuator. Unlike conventional aerodynamic control surfaces, piezoelectric actuators can be highly segmented, individually controlled, and dispersed throughout the wing, features that make them ideal for use with adaptive control laws. One of the early tasks of this project is choosing the best neural network and on-line learning scheme for this application. Another early task is the assessment of digital controller hardware that can accommodate the many inputs and outputs as well as the large amount of computations required for such a control system. Software must then be developed that can perform the neural-network computations and on-line learning. Finally, a testbed wind-tunnel model, having many individually-controllable piezoelectric sensors and actuators, will be built. The accompanying figure shows a schematic for a neural-network-based adaptive control system. Not shown in the figure, but an important aspect of the project is on-line learning. On-line learning allows a neural network to learn the dynamics of the plant. This capability can be used to periodically update the controller during closed-loop testing, or it can provide a simulation model of the plant.

Status/Plans: The primary effort so far has been to perform feasibility studies on the use of neural networks for modeling dynamic systems and to assess the state-of-the-art in digital controller hardware. Data from a recent wind-tunnel test is being used as a benchmark for comparing the capabilities of a variety of network architectures and training schemes. Work is continuing on the modeling of high-order control laws and plant dynamics with neural networks. As more knowledge and experience are gained in the use of these neural networks, on-line learning and adaptive systems will be simulated. Small bench tests will be performed in the ASEB Smart Structures Laboratory and Simulation Laboratory to experimentally validate the concepts developed. With the controller concepts developed and checked out, a wind-tunnel model will be designed and built to demonstrate adaptive flutter suppression.

Figure 93 (a).

NEURAL-NETWORK-BASED SYSTEMS STUDIED FOR ADAPTIVE FLUTTER SUPPRESSION

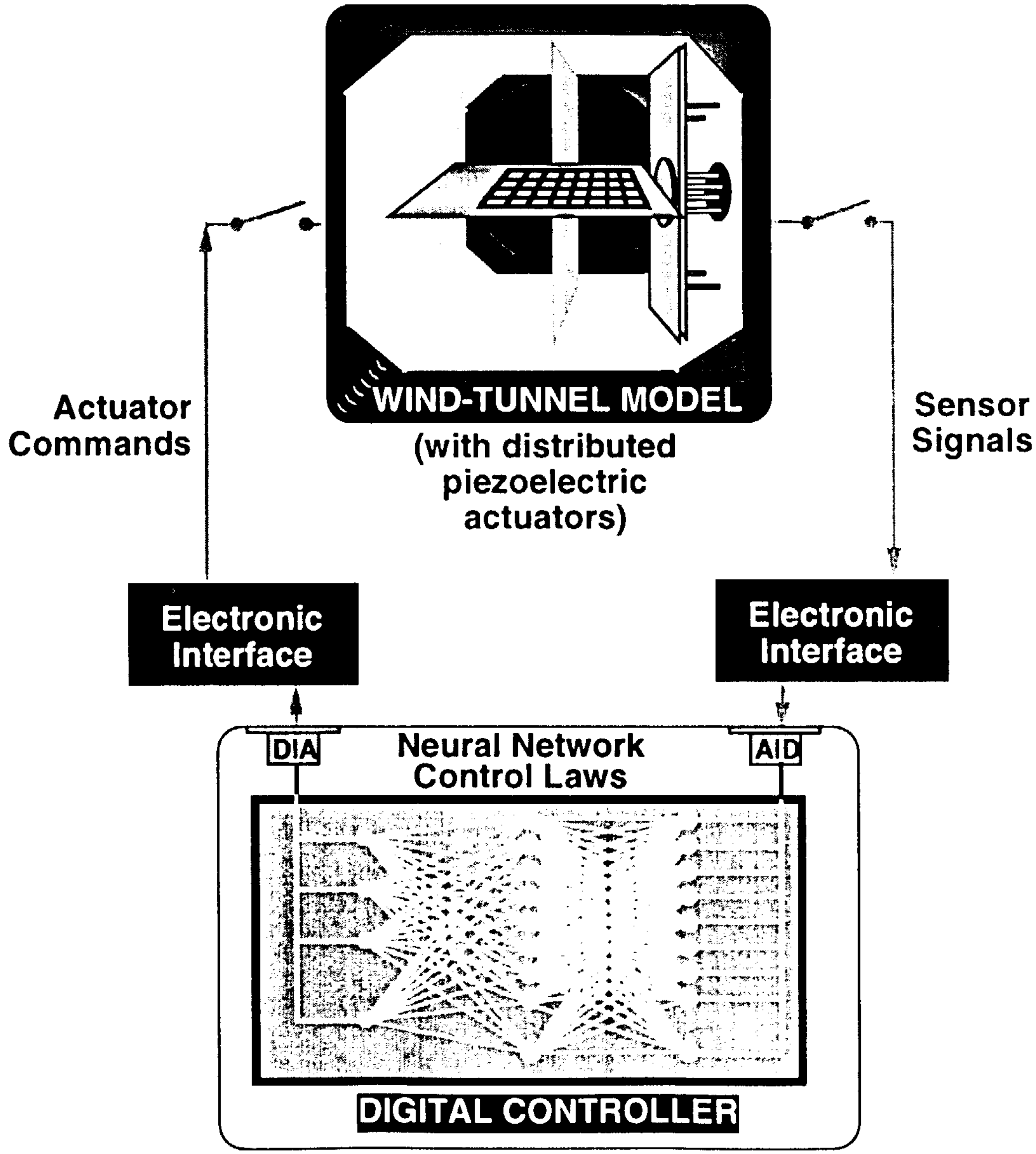


Figure 93 (b).

USE OF ACTIVE MATERIALS AS INTERNAL STRUCTURAL ACTUATORS TO REDUCE TRANSONIC DRAG

Terrence A. Weisshaar
Purdue University

Robert C. Scott
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: The research objective of the present work is to investigate the feasibility of using active internal structural actuators to reduce the steady transonic drag of airfoils and wings.

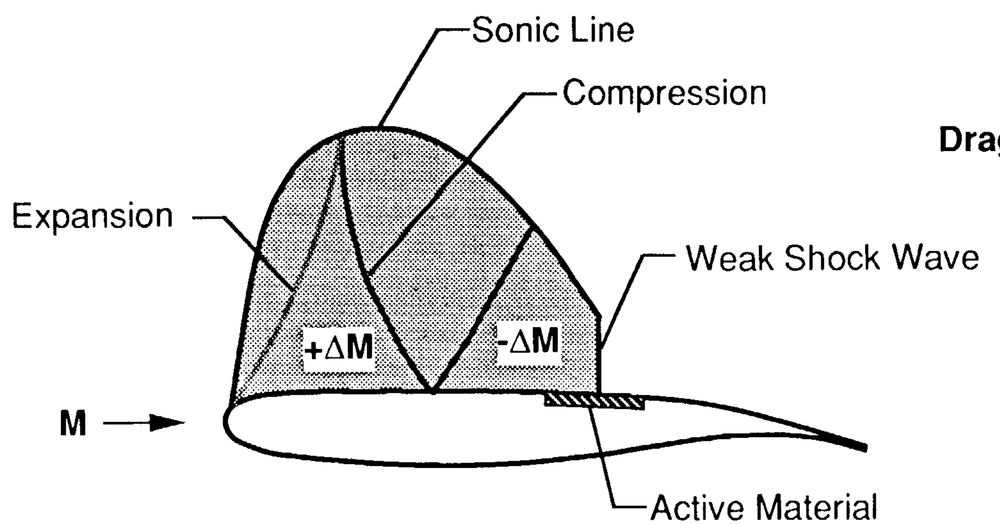
Approach: The approach taken is, initially, to perform analytical studies to prove the feasibility, and then, to conduct wind-tunnel experiments to verify the concept. The flow field around high performance supercritical airfoils, such as that shown in the left of the figure, operating in the transonic flight regime, is sensitive to small local changes in the airfoil surface shape. Such shape changes can be precisely controlled by active internal structural actuators which respond to stimuli such as an applied voltage or a temperature change. As a result of the shape changes, airfoil drag may be reduced, as indicated by the plot on the right side of the figure. Candidate shape-control regions on the airfoil include the nose or leading edge, the extreme portion of the trailing edge and an upper surface region lying between the mid chord and the 3/4 chord. An important early question in this research is how much control can be achieved using these types of actuators and two basic types will be investigated. The first and simplest type is a small actuator patch placed inside the airfoil, such as that indicated in the figure. This type may be made of either a piezoelectric material (that changes shape on command from applied voltage) or a shape memory alloy (that changes shape and stiffness due to temperature changes brought on by resistive heating). The second type of actuator is an active false rib (not shown in the figure). This type looks like a conventional rib element, but has little load-carrying capability unless activated. Investigation of the drag-reduction concept requires two levels of analytical effort. The first level of effort is the development of an analytical model of the first and simplest type of actuator. The second level of effort is the construction of analytical finite element models that very accurately describe the surface distortion of complex built-up wings. Coupled with this effort is the use of an accurate CFD code to predict the flow field around the surface and to estimate the drag.

Status/Plans: The work is still in the initial stage of performing analytical studies. The first and simplest type of actuator has been modeled analytically. An investigation of scaling effects is underway. A finite element model has been developed to simulate an actual wing section with actuators attached. A flow field model has been numerically tested on rigid models. The finite element and flow field models will be combined so that the effects of the actuators on the flow field can be explored. Refinement of these models for use in performing unsteady simulations will follow, with the future hope of using active internal structural actuators to control shock wave oscillations.

Figure 94 (a).

USE OF ACTIVE MATERIALS AS INTERNAL STRUCTURAL ACTUATORS TO REDUCE TRANSONIC DRAG

Supercritical Airfoil



Effect of Active Material on Drag

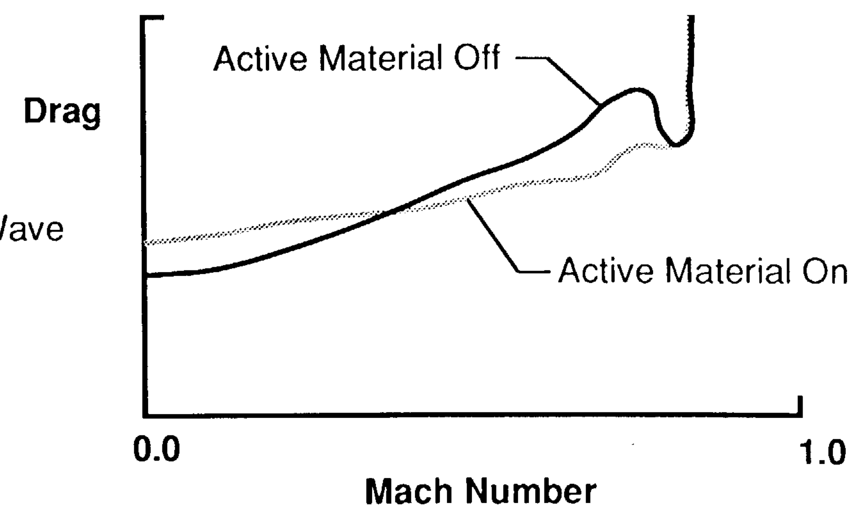


Figure 94 (b).

LANDING AND IMPACT DYNAMICS

F. Y. 1993 PLANS

- Initiate in-house study to assess scaling effects on progressive failure and on ultimate strength of composite beams
- Complete fabrication and installation in Lear Fan aircraft of an in-house energy absorbing composite floor design
- Complete design and fabrication (Phase 2 and 3 task assignment to Lockheed under ACT program) of two 6-foot-diameter composite subfloor specimens using innovative preforms and the RTM process
- Install and checkout runway simulator for Active Control Landing Program (ACLS) research
- Complete joint NASA/USAF/Industry 26 x 6.6 tire friction and wear studies on ALDF
- Complete rolling tire footprint force measurements for 40 x 14 bias-ply, radial-belted, and H-type aircraft tires on ALDF
- Continue development of frictional contact algorithms for aircraft tire analyses

Figure 95

SPACECRAFT DYNAMICS
F. Y. 1993 PLANS

- Controls-Structures Interaction
  - Install multi-axis gimbals payloads and advanced zero gravity suspension system
  - Validate controller designs for optimal pointing on a multi-body platform
  - Complete design and fabricate solar array mast
- Mission Dynamics
  - Validate component mode synthesis methods using existing DSMT analysis and test data
  - Finalize scale model redesign studies to reflect Space Station PIT truss concept
  - Investigate the value of an on-orbit SSF dynamic test
- Base Research and Technology
  - Develop on-line system identification methods for use in adaptive control
  - Install suspension system for flexible manipulator
  - Begin in-house testing of seven degrees-of-freedom flexible manipulator test article

Figure 96

INTERDISCIPLINARY RESEARCH
F. Y. 1993 PLANS

- Support
  - High-Speed Aircraft Integration Research (HiSAIR)
  - Rotorcraft design integration
- Initiate
  - New, HSR-related optimization in HiSAIR
  - Unification of the HiSAIR and HPCCP test application
  - Experimental validation of analytically-designed rotor blades
- Complete
  - Mach 2.4 HiSAIR optimization
  - Integrated optimization of rotor blades including structures, dynamics, and aerodynamics

Figure 97

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The purpose of this paper is to present the Structural Dynamics Division's research accomplishments for F.Y. 1992 and research plans for F.Y. 1993. The work under each Branch (technical area) is described in terms of highlights of accomplishments during the past year and highlights of plans for the current year as they relate to 5-year plans for each technical area. This information will be useful in program coordination with other government organizations and industry in areas of mutual interest.

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